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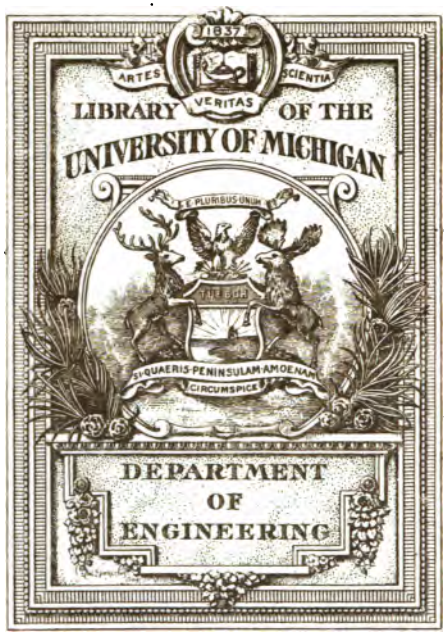
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THE

MANAGEMENT OF DYNAMOS

A Handybook of Theory and Practice

FOR THE USE OF

MECHANICS, ENGINEERS, STUDENTS, AND OTHERS IN CHARGE OF DYNAMOS

BY

G. W. LUMMIS-PATERSON

ELECTRICAL ENGINEER

With Numerous Illustrations

FOURTH EDITION, THOROUGHLY REVISED AND ENLARGED

LONDON
CROSBY LOCKWOOD AND SON
1908

PREFACE.

IN preparing this volume, it has been the aim of the Author to keep in view the requirements of Mechanics, Engineers, Students, and others, who, having (or expecting to have) the charge of Dynamos, desire to make themselves sufficiently acquainted with their construction, as well as with those scientific principles of which some knowledge is required for the intelligent management of the dynamo.

The work—which has been arranged in what appeared to the Author its natural order—may be regarded as consisting of three parts, although these "parts" overlap each other. In the First of such parts, comprising Chapters I. to IV., the elementary theory of the dynamo, and the electrical and magnetic laws and truths affecting its construction, are considered briefly, and only in so

far as they relate to the management of the dynamo: in the Second part, which includes Chapters IV. to VIII., the construction and action of the different classes of dynamos in common use are described: while the Third part — Chapters VIII. to XII.— relates to such matters as affect the practical management and working of dynamos.

For the full theory of the dynamo the reader is referred to the works of Thompson, Kapp, Fleming, and others.

HEATON, NEWCASTLE-ON-TYNE,
June 1895.

PREFACE TO FOURTH EDITION.

IT is now thirteen years since this work was first published, and in this comparatively short period of time the construction of electrical machinery has undergone radical changes, types which were then considered highly efficient and the perfection of scientific design having been displaced by machinery more suited to the present conditions of working, as it is probable that now in use will be displaced by other types in the future. As a consequence, it has been found necessary in the present edition, to eliminate as far as possible all reference to apparatus which has become obsolete since this work was last revised and to include such further particulars and information relating to the management of dynamos as appeared to be of value in bringing the volume up to date. In following out this course it has been

necessary to rewrite certain portions of the work, while considerable additions have been made to the text, which the Author trusts will render the work more serviceable to those interested. The Author is much indebted to those firms who have been good enough to loan blocks for the purpose of illustration.

G. W. L. P.

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THE

MANAGEMENT OF DYNAMOS.

CHAPTER I.

ELECTRICAL UNITS.

Electro-Motive Force. — Electro-motive force, also termed electric pressure, voltage, &c., occupies the same place in relation to electricity as pressure to steam or water. Water only flows from one place to another when there is a difference of level or pressure of water between the two places, and the flow of water takes place from the place of higher level or pressure to the place of lower level or pressure. In exactly the same way electricity only flows from one place or point to another when there is a difference of electrical level or pressure, or an *electro-motive force*, between the two places, and the flow of electricity takes place in a direction from the higher to the lower pressure. The point where the pressure is higher is said to have a *positive potential*, and is usually denoted by the sign + (plus) or P; and the point where the pressure is

lower is said to have a *negative potential* and is denoted by the sign — (minus) or N. Electrical pressure, or electro-motive force, may be produced by chemical action, as in the electric battery; by the motion of electrical conductors in a magnetic field, as in the dynamo; and by numerous other means.

Fall of Pressure.—Pressure in electricity and pressure in steam or water also possess other points in analogy; *e.g.*, in flowing from one point to another they both become less as they recede from the source, or point of higher pressure, in proportion to the resistance met with, or in doing work which may be expressed as resistance. When a current of water flows through a long length of pipe a certain amount of pressure is always lost in overcoming the resistance which the pipe offers to the flow of water. Similarly, when an electric current flows through a long length of conducting cable a certain amount of pressure is always absorbed in overcoming the resistance which the cable offers to the electric flow. If the cable has a uniform resistance throughout the whole of its length, the pressure will fall uniformly; if, however, part of the cable has a greater resistance than another, as may be the case if different portions are made of different materials, or one portion has a greater cross sectional area than another, then the pressure falls most rapidly along the part offering the greatest resistance. The fall of pressure in a "circuit" composed of different resistances is graphically represented in Fig. 1. The portions of the circuit A A A A are composed of copper conducting cable, B is a coil of german silver

wire, and C is an incandescent lamp. The current flows in a direction from the positive to the negative, and, as indicated by the dotted and sloping lines, the pres-

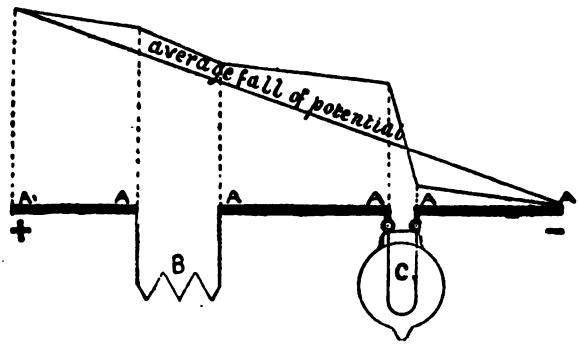


FIG. 1.

sure falls all along the circuit in proportion to the resistance. As will be seen only a slight fall takes place in the copper portions of the circuit, for these being composed of good conducting material offer only a small resistance, as compared with the rest of the circuit; a rather greater fall takes place in the german silver coil, whilst the greatest fall occurs in the incandescent lamp, since this latter has the greatest resistance.

Unit of Electro-Motive Force. — The unit of electro-motive force or electrical pressure is called the *Volt*, and the instrument used in practice for measuring electrical pressure is called a Voltmeter. It is possible by means of suitable machinery to produce almost any desired pressure from a fraction of a volt upwards. The pressures most commonly used in commercial practice vary from .5 volt up to 300 volts in the low tension system, and from

300 volts up to 10,000 volts in the high tension system.

Current. — As electro-motive force or electrical pressure is analogous to *pressure* in steam or water, so is electrical current analogous to the *volume* or *rate of flow* of water passing through or discharging from a pipe or other conduit.

Unit of Electrical Current.—The unit of electrical current is called the *Ampere*, and the instrument used commercially for measuring current strength is the *Ammeter*. Although not strictly correct, we may compare a current of electricity of so many amperes to a current of water flowing at the rate of so many gallons per minute. The ampere is therefore the name given to a particular strength of electric flow, which may be measured in various ways by the effects which it produces, as thermal, magnetic, chemical, &c.

Resistance.—A current of electricity always flows in a conducting circuit when its ends are kept at different potentials, in the same way that a current of water always flows in a pipe when a certain pressure of water is supplied. The same electrical pressure does not, however, always produce a current of electricity of the same strength, nor does a certain pressure of water always produce a current of water of the same volume or quantity. In both cases the strength or volume of the currents is dependent not only upon the pressures applied, but also upon the *resistance* which the conducting circuit offers to the flow in the case of electricity, and on the friction (which may be expressed as resistance) which the pipe offers to the flow in the case of water.

Conductors and Non-Conductors.—No known substance is an absolute non-conductor of electricity, in the same way that no known substance is an absolute non-conductor of heat. Some substances, however, such as wood, glass, slate, ebonite, india-rubber, &c., offer, comparatively, a very considerable resistance, at ordinary pressures, to the electric flow, and are therefore called "*non-conductors*" or *insulators*. Other substances, such as the metals, carbon, water, &c., offer only a very slight resistance to the electric flow, and are therefore called *conductors*.

Laws of Electrical Resistance.—The laws of electrical resistance are very simple, and may be briefly stated as follows:—"The resistance of a conductor is proportional to the length of the conductor, and inversely proportional to the cross section of the conductor, and also depends upon the material of which the conductor is made, *i.e.*, upon its specific resistance."

Unit of Electrical Resistance.—The unit of electrical resistance is called the *Ohm*, and the ohm is defined to be equal to the resistance of 106 centimetres of mercury, 1 sq. millimetre section at zero centigrade. One yard of No. 40 B.W.G. copper wire has a resistance of approximately one ohm.

Ohm's Law.—It has been mentioned above that the strength of an electric current flowing in any circuit is dependent upon the difference of potential maintained between the ends of the conducting circuit, and upon the resistance of the circuit. This relation may be shown exactly by the aid of *Ohm's Law*, which states that "the strength of the current varies directly as the electro-motive force or pressure, and inversely

as the resistance." This law may be expressed algebraically by the following simple equation :—

$$C = \frac{E}{R.} \quad (1)$$

where C = Current in amperes
E = E.M.F. or pressure in volts
R = Resistance in ohms;

or "the number of amperes flowing in a circuit is equal to the number of volts of pressure divided by the number of ohms of resistance" in the entire circuit. Thus if we have a circuit of 1 ohm total resistance, and we apply a pressure of 1 volt, the current flowing in the circuit will be one ampere, thus :—

$$\frac{1 \text{ Volt}}{1 \text{ Ohm}} = 1 \text{ ampere.}$$

If the pressure be doubled the current will also be doubled, thus :—

$$\frac{2 \text{ Volts}}{1 \text{ Ohm}} = 2 \text{ amperes.}$$

The current will also be doubled by halving the resistance, thus :—

$$\frac{1 \text{ Volt.}}{.5 \text{ Ohm}} = 2 \text{ amperes.}$$

The above equation may also be expressed as follows :—

$$R = \frac{E}{C} \quad (2)$$

$$E = R \times C \quad (3)$$

By means of equation (2) the resistance of any circuit can be found if the pressure and current flowing through it is known. For example: if 20 amperes

are passing through a circuit at a pressure of 100 volts, the resistance will be—

$$\frac{E}{C} = R \quad \frac{100}{20} = 5 \text{ ohms.}$$

Equation (3) is very useful as a means of ascertaining the pressure required to send a given current through a given resistance; *e.g.*, the pressure required to send a current of 4 amperes through a resistance of 25 ohms will be—

$$C \times R = E.$$
$$4 \times 25 = 100 \text{ volts.}$$

It will be obvious that as the pressure E is wholly expended in forcing the current C through the resistance R, the above equation (3) also measures the fall of potential in any circuit or portion of a circuit.

Circuits.—An electrical pressure being available, it is necessary, in order to have an electric flow, to provide a continuous conducting path from the point of positive potential to the point of negative potential. This path, whether composed simply of wires, or of lamps, motors, or other applications of electric power, is called a *circuit*, and circuits may be divided into two kinds, viz., *series circuits, and parallel or shunt circuits.* In the series circuit (Fig. 2), the wires, lamps, &c., are arranged end to end, so as to form one continuous conducting path connecting the two points of higher and lower potential, and the current in flowing between these points passes in succession through each of the lamps or other appliances composing the circuit. In the parallel or shunt circuit (Fig. 3), two main wires or leads M_1 M_2 are connected

to the points of higher and lower potential, and the lamps, wires, &c., are connected across the two mains, or arranged side by side so as to form a

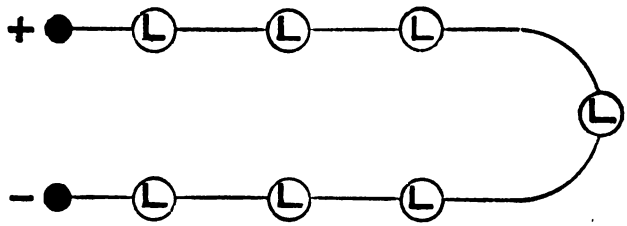


FIG. 2.

number of independent paths or branches, and the current in flowing from the higher to the lower potential divides itself amongst these branches in inverse proportion to their resistance. It will be apparent that the total resistance of the parallel arrangement is less than that of any of its branches, for these being arranged side by side are equivalent

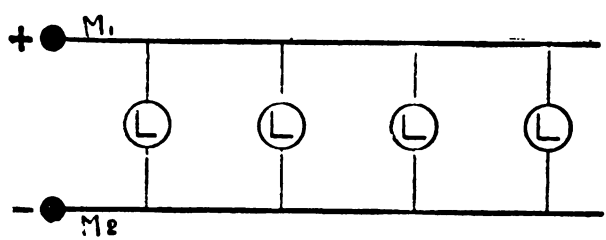


FIG. 3.

to one having a cross section equal to the sum of the cross section of the branches. If the resistances of all the branches are equal, the total resistance of the circuit will be equal to the resistance of one branch divided by the number of branches. The

total resistance of the series circuit is evidently equal to the sum of the resistances of each of its separate parts, since these are included in one continuous path; and for the same reason the strength of the current flowing in a series circuit is obviously everywhere the same. A circuit is said to be "closed" when it forms a continuous conducting path, and to be "open" when a discontinuity occurs in some portion such that an electric current cannot flow. When a circuit is connected or bridged across in such a manner, by some conducting material, so as to offer a resistance less than its normal working resistance, it is said to be "cross" or "short" circuited.

Activity or Power.—The electrical power being developed by a dynamo, or the rate at which work is being done in an electric circuit, may be expressed by any of the following equations :—

$$W = EC \quad (1)$$

$$W = C^2R \quad (2)$$

$$W = \frac{E^2}{R} \quad (3)$$

where E = Electrical pressure or electro-motive force.

C = Current.

R = Resistance.

W = Activity or rate of working.

If E be in volts, C in amperes, and R in ohms, the result will be in *Watts*, the watt being the unit of electric power, and equal to one seven hundred and forty-sixth part of a horse-power. As most installations are in practice provided with an ammeter and voltmeter, the current and pressure may be measured with facility, and therefore equation (1)

is most used in practice in determining the activity or rate of working of an electric circuit. To effect this measurement the instruments are arranged as represented in Fig. 4; D is a dynamo or other generator, the positive and negative terminals of which are connected to the two mains M M, between which the lamps L L are connected in parallel. To indicate the amount of current flowing in the circuit, an ammeter A is inserted in "series" in one of the mains and with the lamps, and therefore the whole of the current passing to the lamps passes through the ammeter, and is

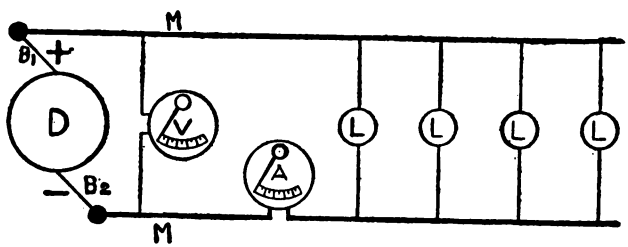


FIG. 4.

measured by the latter. A voltmeter V is connected across the two main leads, or in shunt with the dynamo, and measures the difference of potential between the two mains in volts. By taking simultaneous readings of the voltmeter and ammeter the rate at which energy is being expended in the circuit can be ascertained by equation (1).

For example, suppose the voltmeter to indicate 100 volts, and the ammeter 100 amperes, then by equation (1) $EC = W$. $100 \times 100 = 10{,}000$ watts are being expended in the circuit. The output of dynamos is usually expressed in watts, as this indicates

the actual electrical power given by the machine, irrespective of the strength of the current, or its pressure, which may be varied to any extent so long as their product remains constant. For example, a machine designed for an output of 100,000 watts may be arranged to give 1,000 amperes at a pressure of 100 volts, or 10,000 amperes at 10 volts pressure, or 100 amperes at 1,000 volts pressure. The power required to drive the machine under these varying pressures and currents will remain the same, since their product remains constant. The power required to work incandescent and arc lamps and other electrical appliances is also expressed in watts. A standard candle-power, when produced by an incandescent lamp, requires at the present time an expenditure of 3.75 watts; when produced by an arc lamp, about .5 watts is required. By dividing the output of a machine in watts, by the watts per candle-power as given above, the total candle-power the machine is capable of supplying under the two systems of illumination may be ascertained.

Kilo-watt. — The watt is but a very small unit, and when used for expressing the outputs of the large dynamos in use at the present time leads to inconveniently large numbers; therefore the outputs of such machines are frequently expressed in larger units of 1,000 watts, called *Kilo-watts; e.g.*, a dynamo capable of generating 100,000 watts is called a 100 *Kilo-watt* machine.

Kilo-watt Hour.—The above unit must not be confounded with that employed to measure commercially the electrical energy supplied by central generating stations for lighting and power and other purposes

and known as the *Kilo-watt hour*. In accordance with the stipulations of the Board of Trade, electrical energy when supplied for public purposes in this manner is charged for in units of 1,000 watt-hours, or otherwise Kilo-watt hours; from its origin it is known as the "Board of Trade Unit," and is equivalent to 1,000 watts supplied for one hour, or 2,000 watts for half an hour, or 500 watts for two hours.

Electrical Horse-power.—In practice it is frequently desirable to have the rate of working expressed in horse-power; in this case the electrical power given off is first measured in watts by means of the above formulæ, and afterwards converted into horse-power by dividing by 746, since 746 watts are equivalent to one horse-power. As an example of the practical application of the above, suppose we have a dynamo supplying current to 20-16 candle power incandescent lamps, and we wish to ascertain the horse-power being expended in driving them; then, as each lamp absorbs 60 watts, $20 \times 60 = 1200$ watts are being expended. Dividing by 746 to bring to horse-power, we get 1.6; the electrical horse-power being absorbed by the lamps is therefore 1.6 horse-power.

Mechanical Horse-power. — In calculating the mechanical power required on the dynamo pulley to drive the load in the above example, a further allowance must be made, depending upon the efficiency of the dynamo, on account of the power lost in exciting the dynamo, friction of bearings, &c. Assuming the dynamo to have a commercial efficiency of 85 per cent., the brake horse-power required to drive would be—

$$\frac{1200 \times 100}{746 \times 85} = 1.9 \text{ B.H.P.}$$

CHAPTER II.

MAGNETIC PRINCIPLES.

SINCE the theory of the dynamo is essentially magnetic, it will be necessary, before proceeding to describe its action, to consider the elementary magnetic principles underlying its construction.

The Magnetic Field.—This is the term applied to any space within which the well-known magnetic forces of attraction or repulsion are observable. It is a widely known fact that there is a limited space or area surrounding the ends or poles of a magnet through which small pieces of iron are attracted, or the ends or poles of other magnets are attracted or repelled, and it is to this space that the term "field of magnetic force," or "magnetic field," is applied. The properties of the magnetic force at any point in a magnetic field may be specified, like a mechanical force, by three quantities, viz., the position or point of application, the direction, and the intensity of the magnetic force; of these three quantities the last two only need, however, be considered in connection with the dynamo.

Direction of Magnetic Force.—The direction of the magnetic force at any point in a magnetic field

may be defined as the direction in which a small pivoted magnetic needle points when held in the field at that point. If a small suspended magnetic needle or pocket-compass be placed at various points in the magnetic field surrounding a bar magnet, as

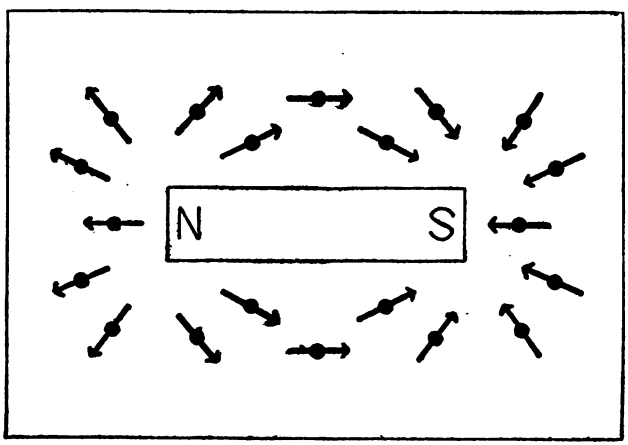


FIG. 5.

represented in Fig. 5, it will be found that the needle always points in a definite direction, which direction varies with its position in the field, the direction of the magnetic axis of the needle at any point representing the direction of the magnetic force at that point.

Lines of Force.—If a magnetic needle, similar to that in the above experiment, be suspended by means of a thread over a bar magnet, and moved from the north to the south pole of the magnet, as illustrated in Fig. 6, the centre of the needle will trace out curving lines connecting the two poles. The paths or

lines followed by the centre of the magnetic needle are termed *lines of magnetic force*, and in the modern conception of a magnetic field this latter is assumed to be entirely filled up with these imaginary lines of force. These lines of force are assumed, for reasons to be hereafter understood, to have a certain positive

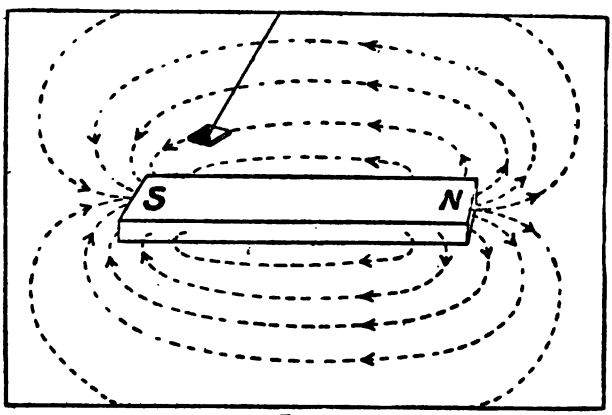


FIG. 6.

direction, namely that direction in which a small north-seeking magnetic pole would tend to move if placed in the magnetic field; or, in other words, the lines of force are assumed to *stream* or *flow* in a direction from the north to the south pole, as indicated by the arrows in Fig. 6.

Intensity or Strength of Magnetic Field.—The relative intensity (and this is all that is required for the present purpose) or strength of a magnetic field at different points may be conveniently expressed by the density or number of lines of force passing through a unit of area at the points in question;

hence where the lines of force are few, the field is weaker than where they are more dense.

Graphic Representation of Magnetic Fields.—The arrangement of the lines of force in any magnetic field may be most expeditiously and conveniently represented by the well known experiment of dusting iron filings upon a sheet of cardboard placed in the magnetic field. In this experiment each of the little particles of iron become magnetised by "induction," and are for the time being transformed into small magnetic needles, which set themselves, in obedience to the attractions and repulsions of the magnetic field, along the directions of the magnetic lines, and

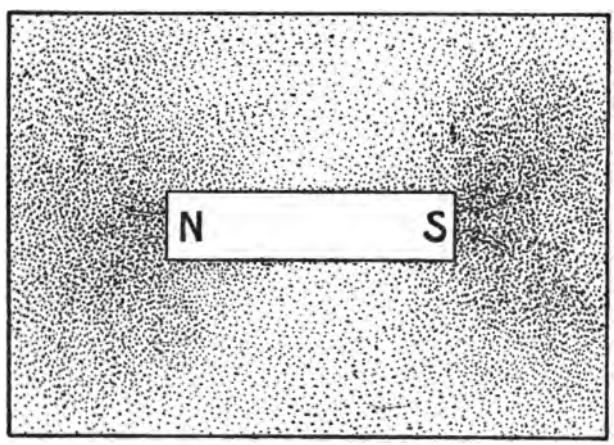


FIG. 7.

thus map out the directions of the magnetic force at every point in the field. The arrangement of the lines of force in the magnetic field of a permanent

bar and horse-shoe magnet, as made apparent by this method, is shown in Figs. 7 and 8. It will be seen that the filings arrange themselves in curving lines

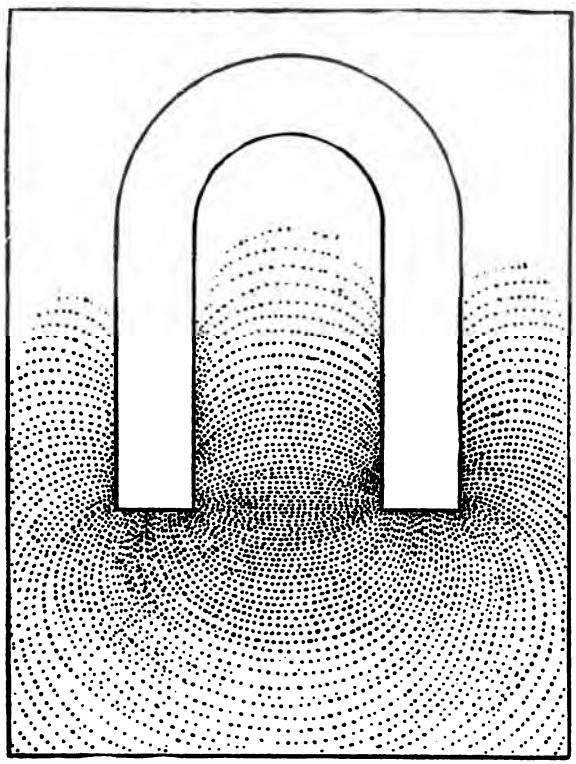


FIG. 8.

connecting the two poles of the magnets. It will also be noticed that the density of the lines and therefore the intensity of the magnetic field is greatest

near the poles or ends of the magnets, and that the strength of the field decreases as the distance from the poles increases.

Electro-Magnetism.—When an electric current is passing through a wire or conductor the wire is found to develop magnetic properties. It creates a magnetic field, and attracts or repels the poles of a magnet, and is attracted or repelled by a magnet,

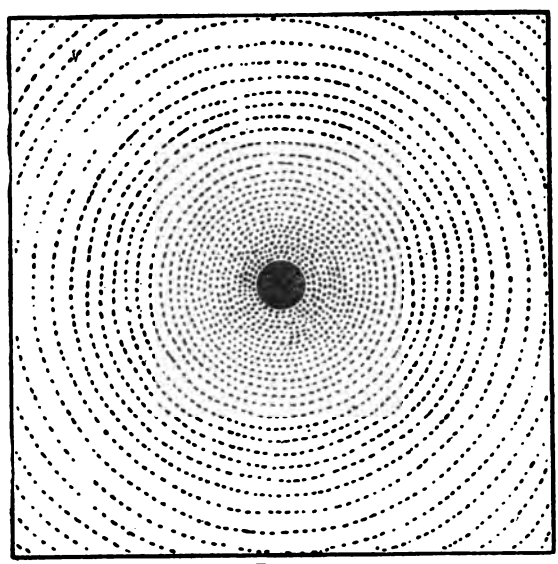


FIG. 9.

according to the nature of the pole and the direction of the current flowing in the wire. The arrangement of the lines of force in the magnetic field surrounding a straight wire or conductor through which an electric current is passing, as made apparent by passing the wire vertically through a sheet of cardboard and

sprinkling iron filings thereon, is shown in Fig. 9. It will be seen that the filings arrange themselves in concentric circles around the wire, and that the strength of the field as represented by the density of the lines is greatest immediately around the wire, and falls off as the distance from the wire increases. The wire is in fact surrounded by a sort of magnetic whirl, which may be observed at any portion of the wire, however great its length, so long as the current is passing.

Solenoids.—If a wire, while being traversed by an electric current, is wound up into a spiral coil, the arrangement becomes a "solenoid." The arrange-

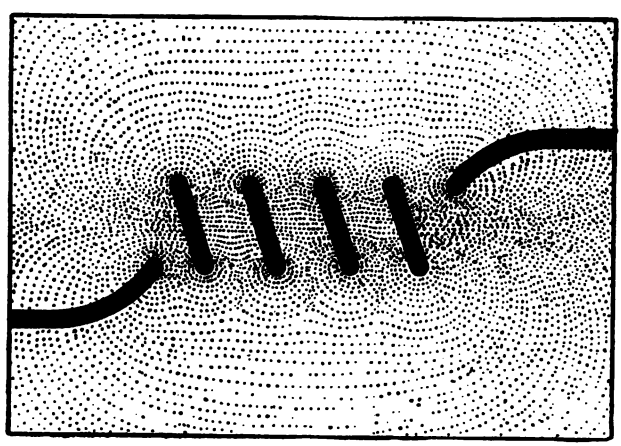


FIG. 10.

ment of the lines of force in the magnetic field surrounding a solenoid is represented in Fig. 10. It will be observed that the lines of force form con-

tinuous closed curves running through the interior of the coil, and issuing from one end and entering into the other end of the coil, and that the arrangement of the external magnetic field is very similar to that of a permanent bar magnet of cylindrical form as represented in Fig. 7. A solenoid has north and south poles, and in fact possesses all the properties of an ordinary permanent magnet, with the important difference that the magnetism is entirely under control, for it is found that under all circumstances the strength of the magnetic field of a solenoid is at every point proportional to the strength of the electric current passing through its coils: if the current is increased, the magnetism is increased in proportion also; and if the current is stopped, all trace of magnetism disappears. The magnetic effect or the magnetising power of a solenoid is also proportional to the number of turns of wire composing the coil; hence the magnetising power of 1 ampere flowing through 10 turns of wire is exactly equal to that of 10 amperes flowing through 1 turn, or to that of 5 amperes flowing through 2 turns. The product of the number of turns of a solenoid by the strength of the current flowing through them in amperes is called the *ampere turns* of the solenoid, and the magnetising power of a solenoid is proportional to the ampere turns of the solenoïd.

Professor Jamieson's Rules.—If the direction of the electric current flowing through the coils of a solenoid is reversed, the polarity of the solenoid is reversed also,—*i.e.*, that which was formerly the south pole becomes the north pole, and that which was formerly the north pole becomes the south pole.

Professor Jamieson has devised two very useful rules, which are especially applicable in the coupling up of the coils of dynamo field magnets, for ascertaining the polarity of a solenoid when the direction of the current flowing through its coils is known, or *vice versa.*

RULE 1.—To ascertain the polarity of a solenoid when the direction of the current in the windings is known: Place the *right hand* upon the solenoid as

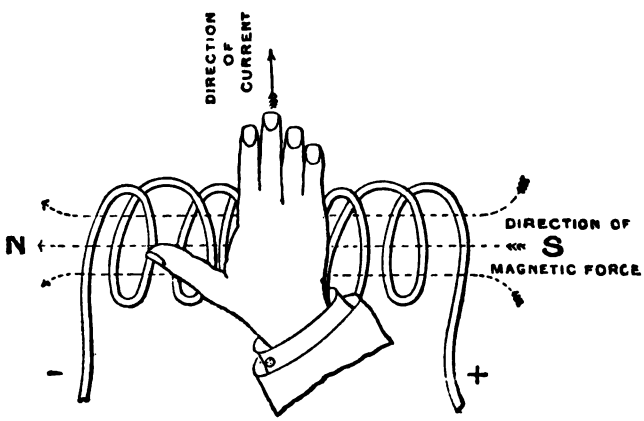


FIG. 11.

shown in Fig. 11, with the fingers pointing in the direction of the current, then the thumb points in the direction of the north pole of the solenoid.

RULE 2.—Ascertain the north pole of the solenoid by means of a compass needle, then by placing your *right hand* upon the solenoid (as shown in the Fig.) so that the outstretched thumb points in the direction of the north pole (or where the magnetic lines leave

the coil), the fingers will point in the direction of the current passing through the windings.

Electro-Magnets.—If, whilst an electric current is circulating in the coils of a solenoid, a mass of iron such as an iron bar is introduced into its interior, it is found that the strength of the magnetic field is enormously increased. This increase in the strength of the field is due to the fact that the iron has a less magnetic resistance than the air, or a greater conductibility for the lines of force, and therefore a greater number of lines pass through the iron than what previously passed through the air. With well annealed wrought-iron the "induction," or number of lines of force, passing through a unit of area of cross section may be increased in the ratio of 1 : 2000, or for every line passing through a unit of area of air 2000 would pass through an equal area of wrought-iron. This property of wrought-iron is taken advantage of in the construction of *electro magnets*, by means of which much more powerful magnetic effects may be produced than by the use of simple solenoids or permanent magnets. An electro magnet is merely a solenoid provided with an iron core of varying form. As previously mentioned, the strength of the magnetic field of a solenoid is strictly proportional to the strength of the current flowing in its coils; this, however, is no longer true when the solenoid is provided with an iron core or becomes an electro magnet, for the reason that the magnetic properties of the iron alters with the strength of the magnetic field. At first, the presence of the iron enormously increases the strength of the field; after a time, however, as the strength of the current flowing in the exciting

coils is increased, the conductibility of the iron for the lines of force appears to decrease, until a point is eventually reached when the presence of the iron core appears to have no effect whatever in increasing the strength of the field. At this stage the iron core may be regarded as being *saturated* with lines of force, and any further increase of magnetising power will produce only a slight increase in the strength of the field, any such increase being that due to the effect of the coils alone acting merely as a simple solenoid.

Curve of Saturation of Electro-Magnet.—The magnetic behaviour of the iron core of an electro-

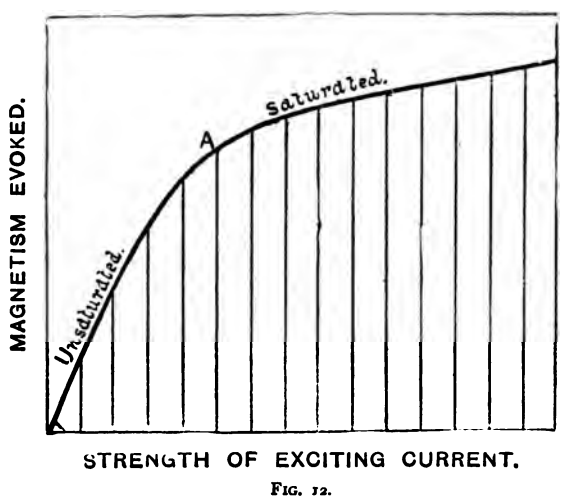


FIG. 12.

magnet can best be studied by reference to Fig. 12, which represents the *curve of saturation* of the electro magnet. The strength of the magnetising current is

represented horizontally, and the magnetism evoked vertically. It will be seen that the curve rises from zero, at first, at a very steep angle, thus showing that a small increase in the strength of the magnetising current produces a great increase of magnetism; after a time, however, as the exciting current is increased, the conductibility of the core for lines of force decreases, and the curve then commences to bend over as at A; as the strength of the exciting current is still further increased the iron core becomes saturated, and adds nothing to the strength of the field, as is indicated by the curve being almost horizontal. The slight increase in the strength of the field, which is indicated by the curve being inclined at a small angle to the horizontal, is due solely to the effect of the coils alone, and it will be noted that a very great increase of exciting current is required at this stage to produce the small effect in the strength of the field indicated.

Residual Magnetism.—This is the term applied to the small amount of magnetism always retained, or *residual* in, masses or bars of iron, or other magnetic substance, which have been magnetised at some period or other (either by means of the electric current or a permanent magnet), and the magnetising agency has been subsequently withdrawn. The residual magnetism so retained by different samples of iron varies in amount with the quality and physical and chemical composition of the iron. Well annealed pure wrought-iron, and soft cast steel of special quality, as a rule possess very little residual magnetism, while on the other hand wrought-iron which contains a large percentage of carbon or other impurities or which has been

subjected to some hardening process such as hammering, rolling, stamping, &c., and cast-iron, possess a very large amount of residual magnetism. In the case of hardened and tempered steel so large an amount of magnetism is retained, under similar circumstances, for an indefinite period, that it becomes known as *permanent* magnetism; it must, however, be understood that this merely refers to a question of degree, as there is otherwise no essential difference between the two in properties. This property of residual magnetism in iron is of great importance in the working of the *self-exciting* dynamo, and is indeed the essential principle of this class of machine.

CHAPTER III.

THEORY OF THE DYNAMO.

THE construction and action of all dynamos is based upon the principle of electro-magnetic induction discovered by Faraday in 1831. Faraday found that currents of electricity are generated in all good electrical conductors by causing them to cut the lines of force contained in a magnetic field.

Cutting Lines of Force.—Reference to Fig. 13 will render clear what is meant by the term "cutting

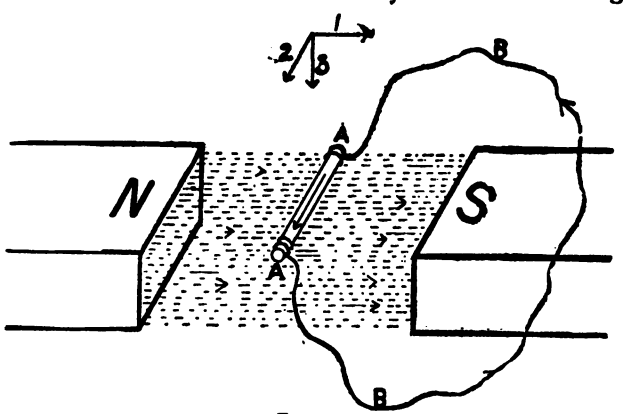


FIG. 13.

the lines of force." In this diagram A A is a conductor, capable of being moved in any direction

through the lines of force proceeding from the north to the south poles of the magnet N S. The two ends of the conductor A A are joined together by the flexible connecting conductor B B, which, not being included in the magnetic field, may be assumed to be removed from its influence. If now relative motion takes place between the conductor A A and the lines of force, it will be at once apparent that the conductor in its motion may either simply *slide* along, or *cut* through, the lines of force. If the conductor is moved along the lines of force in the direction of the arrow (1), *i.e.*, parallel to the lines of force, it will merely slide through the lines without cutting them in any way, and in consequence no electro-motive force or current will be "induced" or generated in the conductor. Again, if the movement is in a direction coincident with the length of the conductor, as indicated by the arrow (2), the motion may again be regarded as merely a sliding one, and again no electro-motive force will be generated. If, however, the conductor is moved downwards in the direction of the arrow (3), *i.e.*, in a direction at right angles to the lines of force, an E. M. F. will be at once induced in the conductor, for the latter in its motion "cuts" through the lines of force. The direction in which the E. M. F. acts, and in which the resulting current flows in the conductor, in the particular case illustrated, is indicated by the arrow marked upon the conducting circuit. The electro-motive force and current thus induced, by the relative motion of a conductor and magnetic field, only exists so long as the conductor is actually cutting the lines of force, and immediately ceases as soon as the conductor

moves out of the magnetic field or the motion itself ceases. In all cases the value of the E. M. F. induced is directly proportional to the rate of cutting lines of force, or to the number cut per second; the greater the speed of the conductor, and the greater the strength of the magnetic field, the greater being the value of

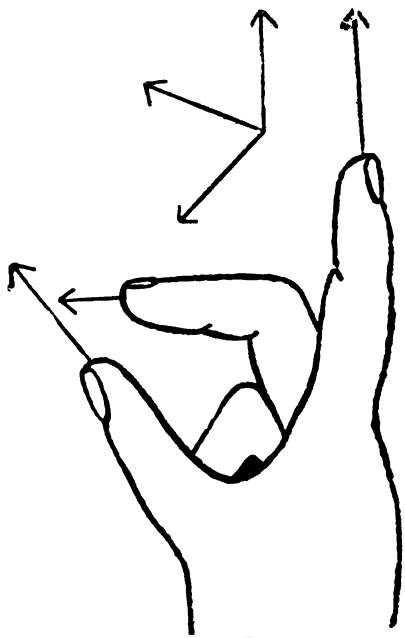


FIG. 14.

the electro-motive force induced. If the direction of motion of the conductor is reversed, *i.e.*, if it is moved through the lines in an upward direction, the direction of the E. M. F. induced in the conductor will be reversed also; or if, whilst the conductor is moving downwards, the direction of the lines of force is reversed by

changing the position of, or reversing the poles of, the magnet, the same thing will occur; from this we see that a definite relation exists between the direction of motion of the conductor, and of the magnetic lines, and of the E. M. F. induced. As in the practical applications of the dynamo it is frequently necessary to refer to this relation, a number of rules have been devised with the object of facilitating its remembrance, of which that due to Professor Fleming, illustrated and described below, is probably the simplest and best.

Professor Fleming's Rule.—Spread out the thumb and first two fingers of the right hand in such a manner that each will be at right angles to the others, as represented in Fig. 14. Then if the thumb be pointed in the direction of motion of the conductor, and the forefinger in the direction of the lines of force, that is, from the north pole to the south pole of the magnet, the middle finger will be pointing in the direction in which the E. M. F. induced in the conductor acts, or in which the current flows.

Simple Dynamo.—We have already seen that the E. M. F. and current induced in a conductor only lasts so long as the conductor is actually cutting the lines of force; hence, in order to keep a current circulating in a conducting circuit by means of this principle, it is necessary to keep the conductor continually cutting the lines of force. This is most conveniently effected by fixing the conducting circuit upon a spindle, and revolving it in a magnetic field. An arrangement of this description is represented in Fig. 15, where A A is a spindle capable of revolving in the magnetic field between the north and south poles of the magnet N S

To this spindle is fixed the conducting circuit C C, the two ends of which are connected to two metallic rings fixed upon the spindle, and insulated from it

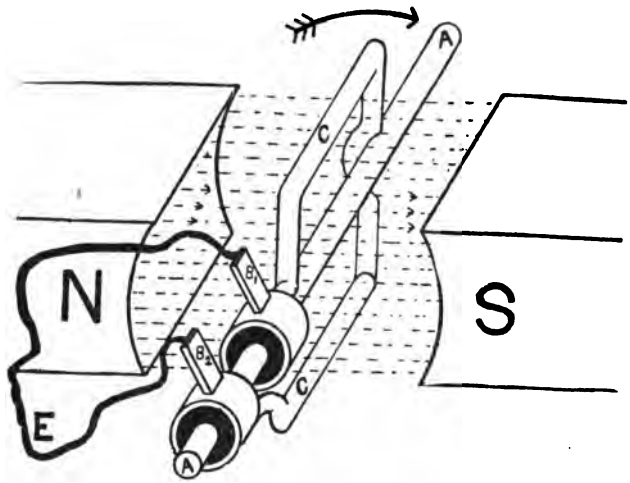


FIG 15.

and from each other. Two brass brushes, B1, B2, press upon each of these rings, and serve to convey the current generated in the conducting circuit C C to the external circuit E. If now the loop be first placed in the vertical plane, as shown, the lines of force will thread through it at right angles. As the loop is moved through the lines of force in the direction of the arrow during a complete revolution, the limbs of the loop will cut through the lines of force; and in consequence, E. M. F.s and currents will be generated in the loop which, on applying Professor Fleming's rule, will be found to be directed as follows:—Whilst the loop is passing from 0° to

180°, or through half a revolution, the E. M. F. and current induced in the limb descending on the right will be directed from back to front, and in the opposite direction, *i.e.*, from front to back, in the limb which is ascending on the left. On passing the 180° position, the limb which was previously descending on the right will begin to ascend on the left, and the limb which was previously ascending on the left will now begin to descend on the right. On passing the 180° position, the limbs will therefore have E. M. F.s and currents induced in them opposite in direction to those which previously flowed through them during the first half-revolution. As a result, the current flowing in the external circuit E will also be reversed at every half-revolution of the spindle, or the current will be an *alternating* current. As the value of the E. M. F., and consequently the strength of the current, generated in the conductor by its motion in the magnetic field is dependent upon the rate of cutting lines of force, or upon the number cut per second, we may examine how this varies during a complete revolution. As the loop moves out of the vertical plane during the first quarter-revolution, it at first moves nearly parallel to the lines of force, and consequently the rate of cutting lines is a minimum. As the rotation is continued, the rate of cutting lines gradually increases, until, upon reaching the horizontal position, the loop moves at right angles to the lines of force, and the rate of cutting lines is therefore a maximum.

Upon moving out of the horizontal position the rate of cutting lines will gradually decrease until a half-revolution has been completed, when the loop

will again be moving parallel to the lines, and consequently the rate of cutting lines will again be a minimum. The same thing will be repeated during the remaining half-revolution, with the difference that the E. M. F. and current will be reversed in direction, as already explained. From this it will be seen that the E. M. F. and current generated in the loop during the first quarter-revolution, or from 0° to 90°, will rise from zero to a maximum value, and then fall to zero again during the completion

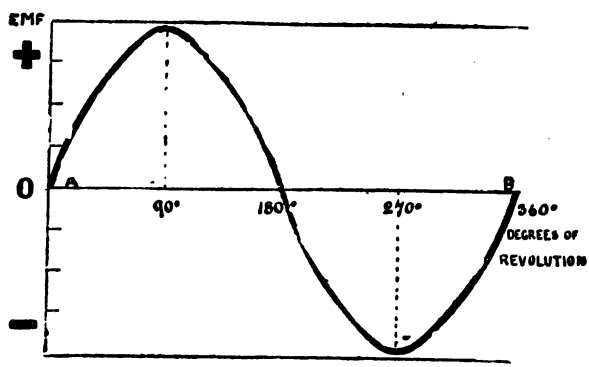


FIG. 16.

of the half-revolution, or from 90° to 180°. From 180° to 270° the E. M. F. will again rise from zero to a maximum, and again fall to zero as the loop moves from 270° to 360°. This rise and fall of the E. M. F. during a complete revolution of the loop is graphically represented in Fig. 16, where the various positions of the loop during a complete revolution are indicated upon the horizontal line A B, which also indicates zero potential, and the vertical lines represent the value of the E. M. F.

set up in the loop at these positions. The portion of the curve above the horizontal line indicates the positive direction of the E. M. F. generated during the first half-revolution of the loop, that portion below the line the reverse negative direction produced by the second half-revolution.

Commutating Current.—The arrangement of the loop or conducting circuit, as described above, constitutes what is known as an *alternating current* dynamo. By far the larger number of the practical

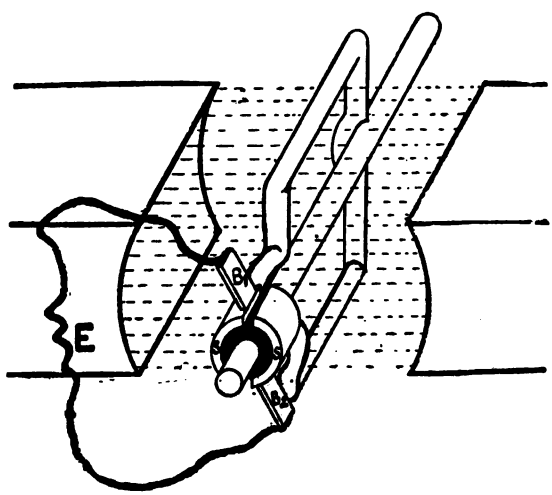


FIG. 17.

applications of electricity are effected, however, at the present time by means of continuous currents generated by *continuous current* dynamos. In this class of machine it is absolutely necessary that the current in the external circuit should flow always in the same positive direction, without reference to the direction it

may take in the armature circuit. In order to effect this, the current as it leaves the armature is caused to undergo a process known as "commutation," the appliance for effecting the alteration in the direction of the current being called a "commutator." This appliance, in its simplest form, consists of two metallic segments S S, insulated from each other by means of a cylinder composed of some insulating material, as shown in Fig. 17. The circuit is arranged upon a spindle as

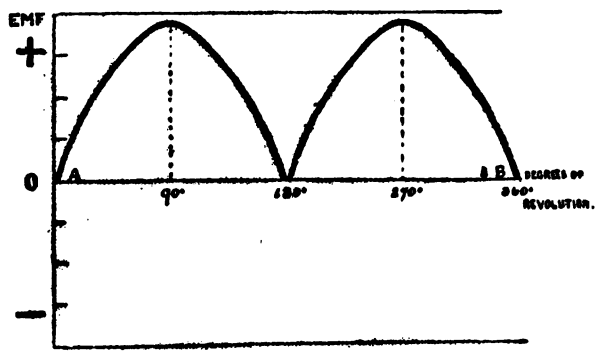


FIG. 18.

before, and the commutator is fixed upon the spindle in place of the two rings, and one end of the conducting coil or loop is connected to each of the segments. Two metallic brushes or springs, B1, B2, press upon the segments, and convey the current generated in the coil to the external circuit E, as indicated. Upon a little consideration it will be apparent that, if the springs are so placed that one segment slides out of contact as the other slides into contact with the brushes, at the moment the current is reversed in the coil, during certain periods

of revolution, the current flowing in the external circuit will be "commutated," or will always flow in one direction, although the relative directions of the current flowing in the revolving coil or loop will be unaffected.

Pulsating Currents.—Although the application of the commutator to the coil has the effect of causing the current to flow always in the same direction in the external circuit, it has no effect whatever upon the *value* of the E. M. F. induced at different periods during a complete revolution of the coil. This still remains as before, as will be seen by reference to Fig. 18, which represents the nature of the E. M. F. generated in the loop when fitted with a commutator. As will be observed, the effect of applying the commutator is simply to cause the E. M. F., which formerly acted in a negative direction, during the second half of the revolution to take a positive direction, as indicated by the second curve incident to this portion of the revolution, being above the zero line (A B) in place of below, as in Fig. 16. The current is now, as indicated by the diagram, a pulsating one, consisting of two sharp impulses to every revolution of the spindle; the current rising from zero to a maximum, and then falling again to zero, though always flowing in one direction so long as the spindle is revolved.

Value of E. M. F.—The electro-motive force set up in any conducting circuit by its motion in a magnetic field is proportional to the speed at which the conductor moves, and to the number of lines of force cut by the conductor, or—

$$E = S\,N;$$

where E = Electro-motive force, S = Speed of conductor, and N = Number of lines of force.

Hence, in order to increase the electro-motive force of the elementary form of dynamo illustrated above, we may increase either the speed of the coil or the number of lines of force threading through it, this latter being accomplished either by increasing the magnetising force applied to the electro magnet producing the magnetic field, or by winding the loop upon an iron core of suitable shape, thus reducing the magnetic resistance of the air space between the poles of the magnet. The E. M. F. may also evidently be increased by winding a greater number of turns or loops around the iron core, each being connected in series with the other, so that the E. M. F. of one is added to that of another, thus making the total E. M. F. of the coil equal to the sum of the E. M. F.s of each of the conductors or loops. The combination of the coil and iron core, when thus arranged, is called an "*armature*," and the electro magnet which creates the magnetic field in which the armature revolves is called the "*field magnet;*" and every dynamo consists essentially of these two parts, and of these two parts and a "*commutator*" when the dynamo is required to generate "direct" or "continuous" currents.

Parts of Dynamo.—The nature and uses of the different parts of a dynamo will be understood by reference to Fig. 19, which represents a complete machine. In this type of dynamo, as in the majority of continuous current dynamos, the magnetic field is stationary whilst the armature revolves in it. The magnetic field in the particular dynamo illustrated is produced by the iron horse-shoe electro magnet M, which is excited by the current

flowing in the magnetising coils E E. The ends or poles of the field-magnet M are bored out so as to form a circular chamber within which the armature A rotates. This latter consists of an iron core rigidly fixed to a steel shaft or spindle S, which revolves in the two bearings F F. Upon one end of the shaft is fixed the driving pulley P.

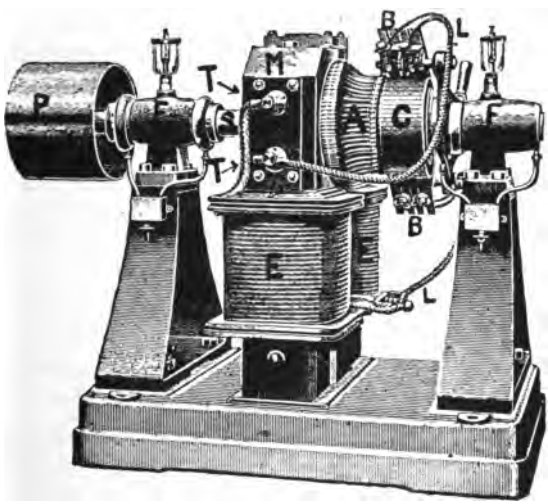


FIG. 19.

The iron core is overwound with a large number of insulated copper conductors or coils, the ends of which are connected to the circular commutator C. Two stationary metallic brushes, B B, press upon the latter, and convey the current generated in the coils of the armature through the flexible conductors or "leads," L L, to the terminals T T, from whence it is conveyed to the external or working circuit.

When the machine is in action, the armatures and conductors or coils are caused to rotate within the magnetic field, produced by the electro magnet M, by means of a belt passing over the pulley P. In consequence, E. M. F.s are induced in the conductors, which, on being commutated at the commutator, are transmitted through the medium of the brushes and flexible leads to the two terminals T T, giving rise to a difference of potential between the latter. This difference of potential may be wholly utilised for the purpose of supplying current to an external circuit, if a separate dynamo is used for exciting the field; or the ends of the field coils may be connected to each of the terminals, when the machine will supply current to its own field magnets. So long as merely an E. M. F. is acting in the armature, and no current is flowing in its conductors, these latter offer no resistance to the motion, and the only mechanical energy expended will be that necessary to overcome the resistance due to the friction of the bearings, &c. As soon, however, as current commences to flow in the conductors, a magnetic field is created around each (as represented in Fig. 9), and this, reacting on the magnetic field produced by the field magnet, exerts an attracting or repelling force, as the case may be, and thus tends to retard the rotation of the armature. In consequence, a greater amount of mechanical energy must be expended in keeping the armature rotating at its normal speed, the amount of energy so expended being directly proportional, if the pressure is kept at a constant value, to the current flowing in the armature.

CHAPTER IV.

ARMATURES.

THE elementary form of armature described in the preceding chapter (Fig. 17) possesses the disadvantage that the current generated in it by its motion in the magnetic field, though always flowing in one direction in the external circuit, is not absolutely continuous, but is a pulsating current consisting of two sharp impulses to every revolution of the spindle. A current of this nature while suitable for certain classes of work, as arc lighting in series, &c., is, however, almost as inapplicable as alternating currents for a large number of other purposes, where in addition to its being requisite for the current to flow always in the same direction, an absolute constancy of voltage must be maintained. It therefore remains to so arrange matters that this constancy of voltage is assured, this being effected by the multiplication and suitable arrangement of coils upon the armature as described below.

Continuous Current.—From what has been already described, it will be apparent, that as the pulsations of the current in the elementary form of armature are due to the coil moving alternatively into, and out of, the positions of best and least action in the magnetic field,

if the construction be so modified that an additional coil is arranged at right angles to the existing coil, with its ends suitably connected to a four-part commutator, so that one coil is in the position of best action, whilst the other is in the position of least action in the magnetic field, the resulting current will be more nearly continuous.

That such is the case will be seen by reference to Fig. 20, which represents the resultant curve due to such a combination of coils; it will be seen that the

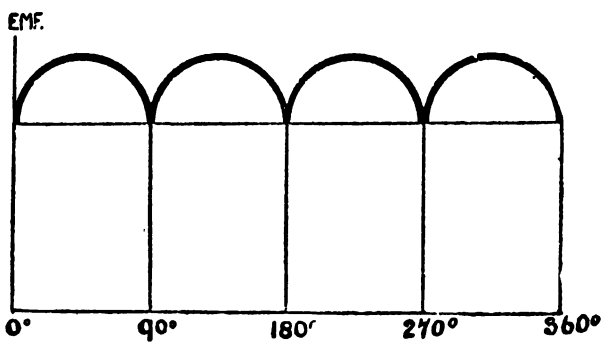


FIG. 20.

crests of the curves are much closer together, and approach more nearly to the straight line, which would represent the current if it were absolutely continuous. A little consideration will show that if we thus keep on arranging coils between the existing ones, and suitably altering the construction of the commutator by arranging additional segments to accommodate the ends of these coils, a time will eventually be reached when the curves so overlap each other that they may be represented by a practically straight line, when the

resulting current will be, to all intents and purposes, continuous. It is upon this principle that the armatures in practical use are constructed, a large number of coils being employed, suitably arranged upon an iron core, so that a large proportion of them are always actively cutting the lines of force, or moving in the positions of best action in the magnetic field.

Types of Armatures.—There are several different methods of arranging the coils upon the iron armature, but the object of all of them is to obtain the practical continuity of the current. The types of armature in most extensive use at the present time are the following:—

The Ring or Gramme Armature, in which the coils are arranged upon an iron ring.

The Drum or Siemens Armature, in which the coils are arranged upon the surface of an iron cylinder or drum.

Each of these forms of armature has its own special advantages for particular purposes, but in a general way it may be said that the drum type is electrically and mechanically the more efficient of the two, possessing as it does, possibilities in the way of the better mechanical construction of the core, and in the arrangement and fixing of the conductors thereon not to be found in the ring form. The proportion of active conductor in its windings is also much greater, in the drum type, while from the nature of the construction of its core, it is more efficient in the conduction of the magnetic lines from pole to pole of the field magnet, thus necessitating a smaller, and therefore lighter, construction of the armature, and in less wire and exciting

current being required for the field magnets, for a given output, over the ring armature. These properties cause the drum form of armature to be very extensively employed in the best class dynamos and motors of the present time.

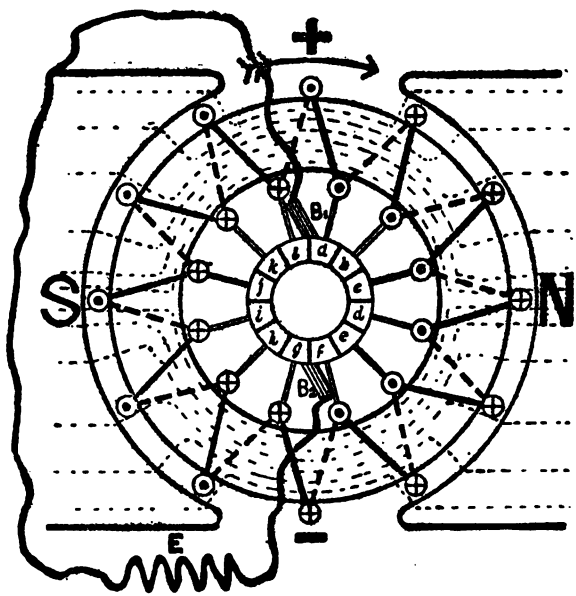


FIG. 21.

The Ring or Gramme Armature.—The principle of this armature is shown diagrammatically in Fig. 21. An iron ring capable of revolving upon an axis is arranged in the magnetic field between the poles N and S of an electro magnet. Upon this ring is wound a number of coils or loops of insulated copper

wire, so as to cover the whole of the surface of the iron ring. The ends of each of the coils are connected to the ends of adjacent coils, so that a continuous closed spiral is formed all round the ring; and at the points where connection is made between the coils, connection is also made to strips of copper which are insulated from each other, and arranged around the axis of rotation into a circular commutator, as shown in the figure. Against the two strips situated at opposite ends of a diameter press two metallic brushes, B1, B2, which, remaining stationary, serve to convey the current generated in the coils of the armature to the external circuit E. The arrangement of the lines of force in the magnetic field between the two poles N and S, when the ring is inserted therein, is shown by the dotted lines in Fig. 21. From this it will be seen that the lines of force issuing from the north pole pass by way of the armature core to the south pole of the magnet, one half of the lines passing through the upper portion of the core, and the other half passing through the lower portion of the core. Owing to this peculiar arrangement, a very intense magnetic field is created between the outer surface of the armature core and the polar faces, whilst the interior space within the core remains almost entirely free from lines of force.

If the armature core be rotated in the direction of the arrow, the whole of the conductors, being immovably fixed to the core, must necessarily partake of the movement; and therefore all the conductors arranged upon the exterior surface of the ring, moving in the magnetic field in the spaces between the outer surfaces of the ring and the two polar faces, will cut the

lines of force contained in this magnetic field, and therefore E. M. F.s will be generated in each of the conductors in consequence. The directions in which these E. M. F.s act, as found by Professor Fleming's rule, is indicated by the dots and crosses marked upon the conductors in Fig. 21. The dots represent the direction of the E. M. F.s when acting from back to front, and the crosses the direction when acting from front to back. As will be seen by this indication, in the conductors moving in the left-hand space the E. M. F.s are directed from the back of the armature to the front, whilst in all the conductors moving in the right-hand space the E M. F.s are directed from the front to the back of the ring. As we saw in the elementary form of armature described in Chapter III., no E. M. F.s will be induced in the conductors moving in the spaces at the top and bottom of the ring between the two poles of the magnet, for these conductors are moving parallel to the lines of force, nor will any E. M. F.s be generated in the conductors arranged upon the interior surface of the armature, since these conductors are removed from the influence of the lines of force. These interior conductors, although inactive in the production of E. M. F.s, are essential however for the connection of the various active conductors one to another. The coils shown upon the ring in Fig. 21 being wound right-handedly, it follows that the E. M. F. induced in each of the conductors upon both sides of the ring will be added to that of the next above it; consequently the E. M. F.s in all the conductors upon each side of the armature will be directed from the bottom to the top of the ring, which will therefore

have a higher or positive potential, whilst the bottom of the ring will have a lower or negative potential, as indicated by the signs in the figure. It will be apparent that if the coils were wound left-handedly, just the reverse would take place, the E. M. F.s being all directed from the top to the bottom; or the same thing would occur if the right-handed winding were retained, and the direction of rotation reversed. Since the total or resultant E. M. F.s of each side of the armature is equal to the sum of the E. M. F.s generated in each of the conductors arranged upon either side of the armature, it follows that if these latter are equal in number the resultant E. M. F.s will be equal and opposite; and, consequently, if the external circuit is open, no current will flow in any portion of the windings, the E. M. F.s merely giving rise to a difference of potential between the top and bottom of the ring. If the external circuit is closed, the current which results will, owing to the two halves of the ring being in parallel, flow up the windings on each side of the ring to the top brush, and from thence through the external circuit to the bottom brush, and thus complete the circuit.

The Drum or Siemens Armature.—This type of armature differs essentially from the ring armature only in the manner in which the conductors are arranged upon the iron core. In the ring armature the core consists of a ring, and is overwound with conductors passing along the outer surface and through the interior; in the drum armature, the core is in most cases a ring also, or may be regarded as a ring, and is overwound with conductors passing along the outer surface, but in place of passing through the

interior the conductors are carried completely around it axially, in the manner represented in Fig. 22. This shows a drum armature in perspective, upon which only two adjacent conductors or coils have been wound. Since the windings of the drum armature pass over the ends of the core, it is impossible to represent the whole of them in perspective, and there-

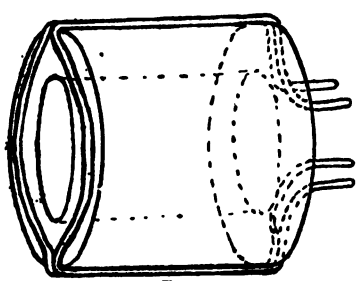


FIG. 22.

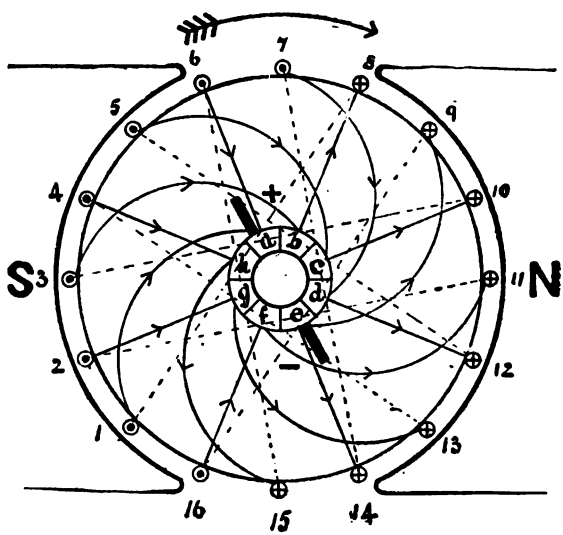


FIG. 23.

fore they are exhibited diagramatically in Fig. 23, which illustrates what is known as a right-handed

winding, with eight-part commutator. In the figure shown, the windings are supposed to be viewed from the commutator or front end of the armature. The windings passing along the length of the drum are represented by the small circles, upon which are marked the dots and dashes denoting the direction of the E. M. F.s induced in the conductors, as in the ring armature. The connections passing across the back end of the drum are represented by the dotted lines, those upon the front end by the full lines. The manner in which the individual loops or coils are arranged and connected to each other and to the commutator, will be rendered clear by following the course of a single loop or coil upon the armature. Starting from the commutator segment (*a*), upon which the positive brush is resting at the upper portion of the armature, the conductor proceeds up the face of the drum to 6, thence along the top and across the back end to the lowest point of the drum, from whence it proceeds along the bottom of the drum to 15. From 15 the conductor is brought round the face of the drum and connected to the commutator segment (*h*), next to the one from which it started. Another coil starts from the segment (*h*), and follows a similar course upon the surface of the armature, and is connected to the segment (*g*), from which another coil starts, and so on all round the armature. A continuous closed spiral is thus formed all round the armature, in a somewhat similar manner to the ring armature. The arrangement of the lines of force in the magnetic field, when the armature is inserted therein, is similar to that of the ring armature; and with the armature rotating in the direction

indicated by the arrow, it will be seen that the E. M. F.s and currents induced in the conductors, on either side of the armature, have the same relative directions as those induced in the conductors arranged upon the outer surface of the ring armature, the only difference being that the current flows across each end of the drum in place of flowing through the interior; the conductors at the ends being thus the

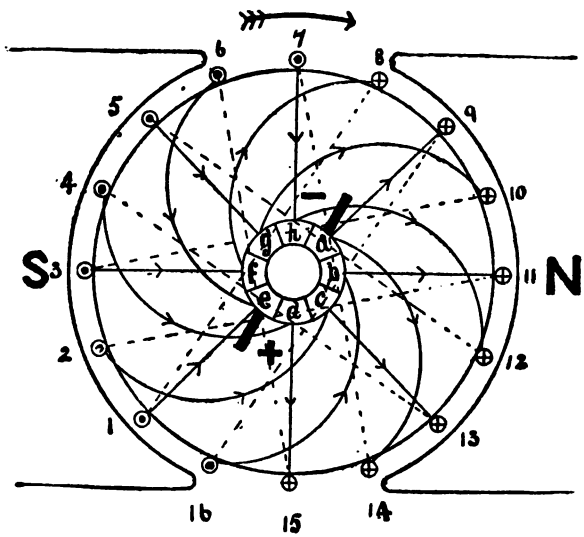


FIG. 24.

only idle portions of the winding in the drum armature. With the particular winding shown in Fig. 23, *i.e.*, a right-handed winding, the E. M. F.s will be directed from the bottom to the top of the armature, in a similar manner to the ring armature, the direction of the E. M. F.s being reversed by reversing the

direction of rotation, or by employing the left-handed winding shown in Fig. 24.

Multipolar Ring and Drum Armatures.—In practice it is found that although the ring and drum forms of armature, revolving in a bi-polar field, as described above, forms a most efficient arrangement for moderate outputs up to about 180 kilowatts,

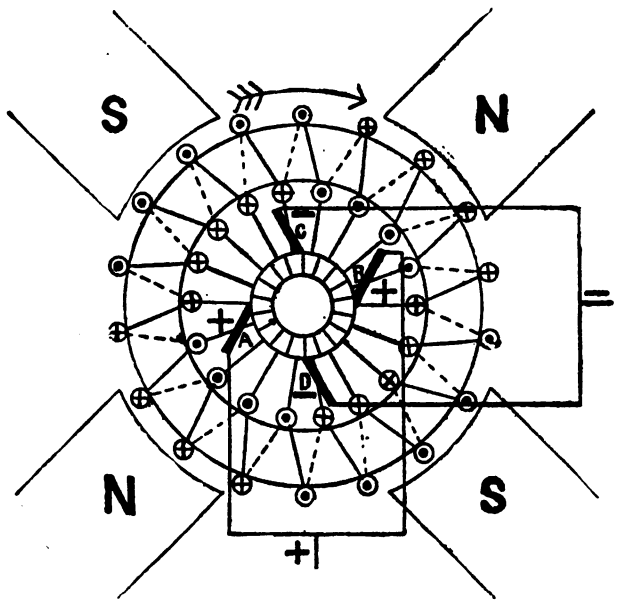


FIG. 25.

when larger outputs are required from a single machine it is more economical to arrange the armature in a field composed of 4, 6, 8 or more poles. In this case the conductors are arranged upon the surface of the ring and drum cores so as to form closed

spirals as before, the only difference being that the number of neutral points, or points of collection of the current upon the commutator, is increased in proportion to the number of poles; and in the case of drum armatures, that the loops or coils span a smaller

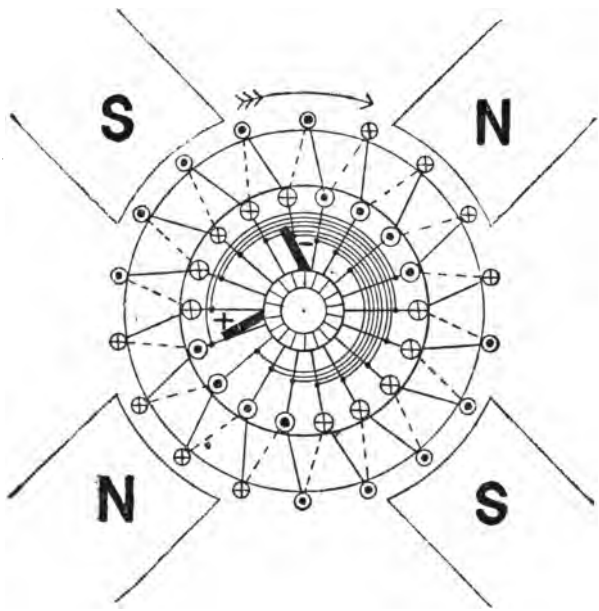


FIG. 26.

proportion of the circumference of the armature. Referring to Fig. 25, which represents a ring armature rotating in a 4-pole field, it will be seen that the coils are arranged upon the core, and connected to the commutator in precisely the same manner as the bipolar ring armature described above. The multipolar

armature, as shown, differs however in the fact that when rotating, it produces two places at equal positive potentials and two places at equal negative potentials upon its commutator, at which the current may be collected, these points being indicated by the position of the brushes in the figure. To collect the current, the two brushes (A B) at equal positive potentials, and the two brushes (C D) at equal negative potentials, are connected together and to the external circuit, as represented. Another method of connecting, which necessitates the use of two brushes only, is illustrated in Fig. 26. In this arrangement, such bars of the commutator as are at the same potentials are connected together. In the case of a 4-pole armature, each of the commutator bars are electrically connected to the one situated diametrically opposite, and the positions for the brushes are at right angles, as represented in Fig. 26; in a 6-pole armature, the three segments of the commutator, situated at 120° apart, are connected together, the brushes being placed 60° apart.

Multipolar Drum Armatures.—Figs. 27 and 28 represent diagramatically the windings of multipolar drum armatures when arranged in parallel and series groupings respectively. In the former grouping, the windings are arranged in as many parallels as there are poles; in the 4-pole field illustrated, the armature is therefore equivalent to a pair of bi-polar drum armatures, each carrying half the total current. The same sequence of winding is used as in the bi-polar drum armatures (Figs. 23 and 24), the only difference being that the wires passing over the ends of the core span approximately only one-quarter in place of one-half

the circumference of the armature. In the series grouping (Fig. 28), the windings are arranged in two parallels, with any number of poles; the total E. M. F. of the armature is therefore equal to the sum of the E. M. F.s induced in the conductors, arranged in series between the brushes as in the ordinary bi-polar drum

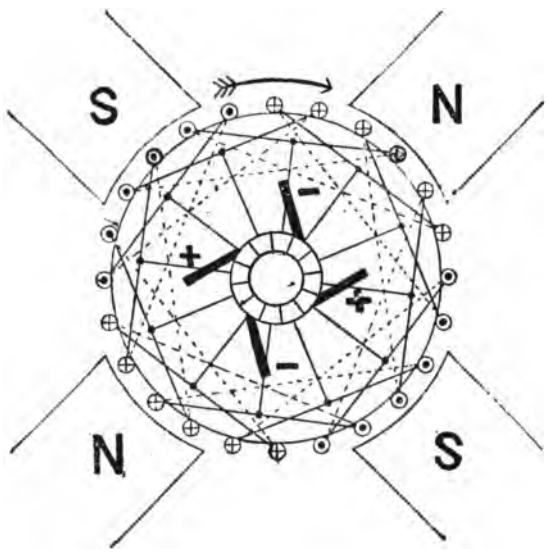


FIG. 27.

armature. Since in this grouping the windings are arranged in two parallels, it follows that two sets of brushes only are required, without any cross connecting of the commutator. Their position upon the commutator varies with the number of poles; when the field magnet consists of 4 poles, the brushes are placed 90° apart, or at right angles, as represented in

Fig. 28; when consisting of 6 poles, the brushes are placed at opposite extremities of a diameter of the commutator as in bi-polar armatures; and when consisting of 8 poles, they are placed 45° apart.

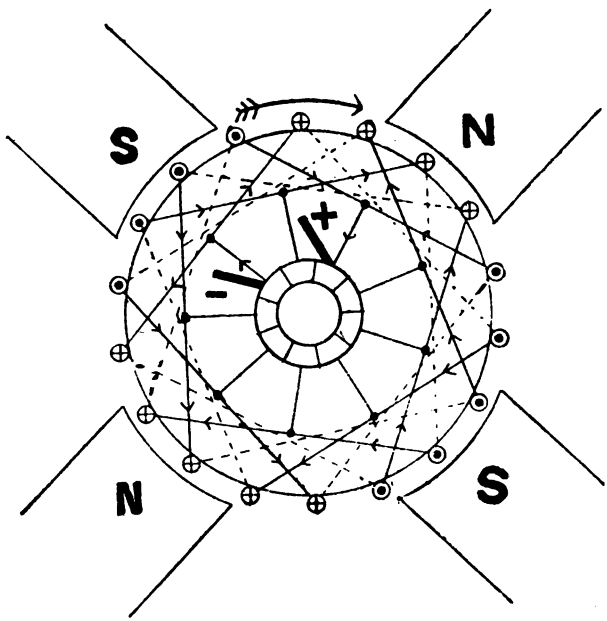


FIG. 28.

Armature Windings in Parallel.—In dynamos intended to generate exceptionally large currents, often required for use in metallurgical processes, difficulties in efficient commutation are sometimes experienced if the armature is wound with the ordinary series or parallel windings. In consequence

it is sometimes convenient to arrange two or more separate and distinct windings on the armature, each winding being connected to its own set of commutator bars, all sets being interleaved in one commutator, so that each alternate bar is connected to one or other of the separate windings. The current is then collected by a pair of brushes, or set of brushes, connected together so as to virtually form one broad brush, connecting the windings in parallel. It is not the usual practice to arrange more than three sets of windings in parallel in this manner, when, of course, the brushes, or each set of brushes, must be made to overlap not less than three bars of the commutator. The division of the very stout conductor, required for a single circuit, into several smaller conductors, arranged as in this method of winding, tends to reduce eddy currents, and the arrangement further has the advantage that an accident to one winding does not necessarily disable the machine, but only reduces its current capacity. Trouble, however, is likely to be experienced if the brushes are not firmly bedded down so as to span the requisite number of commutator bars, owing to the liability of one or more of the circuits being opened while the machine is running, resulting in sparking.

Position of Brushes on Commutator.—In all dynamos, both bi- and multipolar, there are certain positions upon the commutator at which the brushes may be placed with a minimum of sparking. These positions are called the *neutral points*, and, as will be seen on examination of Figs. 21 to 28, the position of these neutral points varies with the type of field

magnet and winding of armature. In ordinary bi-polar dynamos the neutral points lie at opposite ends of a diameter of the commutator, which diameter is called the *neutral line.* In most dynamos these neutral points do not occupy a fixed position upon the commutator, but vary their position from time to time as current is taken from the machine. When the armature is not supplying current to the external circuit, the neutral line, in bi-polar dynamos, occupies a position at about right angles to a line joining the middle of the pole pieces, or at right angles to the direction of the lines of force in the armature; but as current is taken from the armature, the neutral line shifts round in the direction of rotation, when the brushes must also be shifted round through a certain angle to the corresponding neutral points, if sparking at the brushes is to be avoided. This alteration in the position of the brushes is known as the *lead*, and the angle through which they are moved as the *angle of lead*, and is in all dynamos "forward," or in the direction of the rotation of the armature; in motors, however, it is in the opposite direction or "backward." The degree of lead, or its absence, determines the quality of a dynamo or motor as an efficient machine; in good ordinary dynamos the lead ought to be very slight, while in the case of machines of the best class, it is frequently totally absent, and the machine may be run at all loads within its capacity without any attention being required to adjust the brushes.

Causes of Sparking.—Sparking at the brushes of a dynamo is due to several causes, but mainly to the short-circuiting by the brushes of the armature coils while actively cutting the lines of force. An inspec-

tion of Figs. 21 and 23 will show that the ends of each of the coils of the armature are connected to two adjacent segments of the commutator, and that each of the brushes is sufficiently broad to bear upon two bars of the commutator. Hence when each of the coils, during a certain period of the revolution, passes underneath the brushes, each will be momentarily short-circuited by the brushes bridging across the two segments to which the ends of the coils are connected. If this short-circuiting takes place while the brushes are on the neutral points, the coil will be moving mostly parallel to the lines of force, the E. M. F. acting in it will be almost zero, and, in consequence, no sparking will result. If however the brushes are shifted out of the neutral points, either to the right or left, the coil will be short-circuited whilst still actively cutting the lines of force, and an E. M. F. will consequently be acting in the coil. This E. M. F., though small, may produce a very large current, momentarily, owing to the very low resistance of the short-circuited coil. When therefore the short-circuit is opened by the rotation of the commutator, this current, owing to its property of "self-induction," or "electric inertia," does not immediately die out, but continues to flow across the gap for a brief interval, and expends its energy in the form of sparks, which rapidly wear away the commutator and brushes.

It is possible, by suitable means, such as interposing a counter E. M. F. in the form of coils wound in a direction contrary to and adjacent to the active coils, and connected in series with the latter and the commutator segments to which they are connected, to

entirely prevent the sparking due to this cause, but this method, which is due to Sayers, in common with others of a similar character, is not generally adopted owing to its expensive nature. More recently the use of an arrangement of small supplementary poles, variously termed *commutating* or *compensating poles*, has been suggested, and as these are of a simple character, and not expensive in application, they have been extensively adopted, and found to be eminently satisfactory in practice, under certain conditions. These commutating poles take the form of small auxiliary or "inter-poles," arranged between the main magnet poles, upon the lines of commutation or neutral lines, and their use is to provide a special commutating field whereby the E. M. F. induced in the short-circuited coils undergoing commutation at any instant, is neutralised, and thereby sparking entirely prevented. Sparking may be much reduced if not altogether prevented, by the use of brushes of suitable form, composed of a large number of fine wires, none of which are, individually, of sufficient diameter to short-circuit the segments. The use of brushes composed of carbon blocks is also efficacious in the prevention of sparking.

Distortion of Magnetic Field.—When a dynamo is running without load, and merely giving rise to a difference of potential between its terminals, and when practically no current is flowing in its armature coils, the magnetic lines, passing through the armature core from pole to pole of the field magnets take approximately the paths as indicated in Fig. 21. As soon, however, as current begins to flow in the armature conductors, an immediate re-arangement of the lines

takes place, which has an important bearing on the working of the dynamo, since it involves the shifting of the neutral points, and consequently, in many dynamos and motors, the shifting of the brushes, in order to secure sparkless collection of the current.

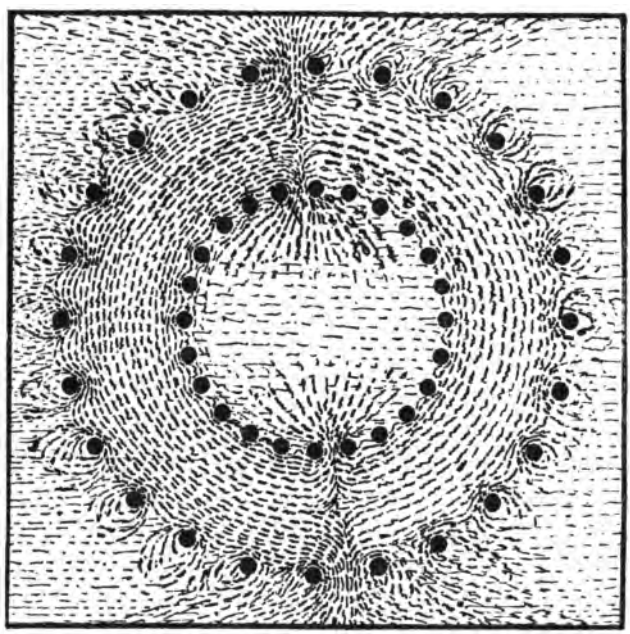


FIG. 29.

This distortion of the magnetic field is directly due to the fact that the armature, when working, becomes itself an electro magnet, the poles of which exert an attracting or repelling force upon the magnetic field. The nature of this armature magnetism will be understood

by reference to Fig. 29, which represents the field due to a ring core; the external arrangement of the lines produced by a drum core is, however, practically the same.

Upon referring to Fig. 21 it will be seen that the currents generated in the windings on each side of

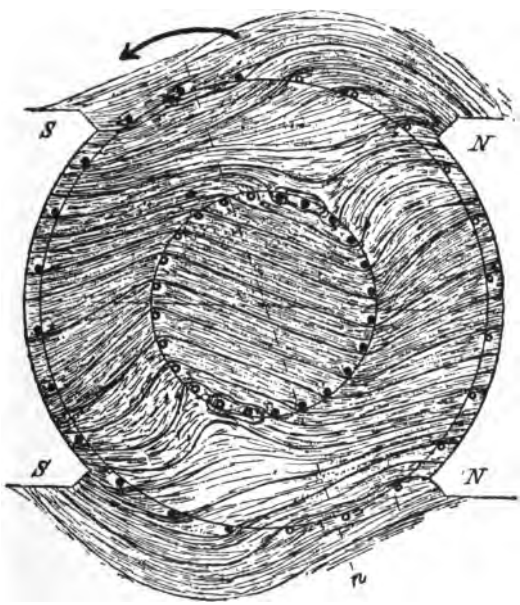


FIG. 30.

the armature, by its motion in the magnetic field, are flowing from the bottom to the top of the ring. On applying the rule given on page 21, it will be found that these currents tend to produce north and south poles on each half of the core at the points where the current enters and leaves the armature. There will

thus be two north poles at the top of the ring, and two south poles at the bottom; but as these poles are in juxtaposition to one another, the external effect will be equivalent to a single north and south pole situated at the top and bottom of the ring. The resultant effect of these two armature poles upon the magnetic field is to twist the lines of force round into an oblique direction, as indicated in Fig. 30. Since in order to secure sparkless collection of the current, and to obtain the greatest difference of potential between the brushes, it is necessary to place these latter at points situated at right angles to the direction of the lines of force in the armature, this twisting of the lines necessarily involves the shifting of the brushes round the commutator in the direction of rotation, otherwise the armature coils will be short-circuited by the brushes while actively cutting the lines of force, and considerable sparking at the brushes will result.

Eddy Currents.—Another very important reaction which occurs when the dynamo is working, is the production of *eddy currents* in different parts of the machine. This term is applied to the currents which are always produced when a solid metallic mass is rotated in a magnetic field, or is subjected to the action of a magnetic field which is undergoing change in its intensity or strength, for the reason that the currents generated always tend to flow in more or less circular paths. When produced in large solid metallic masses, the strength to which these eddy currents attain is frequently very considerable, owing to the low electrical resistance of the masses in which they flow; and in addition to consuming a large amount of energy, they frequently occasion a large and dangerous

rise in the temperature. The cores of armatures being made of iron, are, unless suitably constructed, subject to the detrimental influence of these eddy currents, as is also the case with the conductors wound upon the core if these are of large cross-sectional area. To entirely prevent the generation of these eddy currents is impossible; they can, however, be prevented attaining any considerable strength, by suitably interposing resistance in their path. With this object, the cores and conductors of armatures are *laminated*, or subdivided into a number of small parts, each of which is electrically insulated from the other by some insulating material.

CHAPTER V.

ARMATURES IN PRACTICE.

HAVING in the preceding chapter considered the principles and action of the two types of armatures at present in most extensive use, it now remains to describe briefly in detail the practical construction of such armatures.

Armature Cores.—The cores of all practical armatures are now invariably *laminated*, or constructed of iron wire, ribbon, or discs. This method of construction is adopted in order to minimise as far as possible the generation of eddy currents, which otherwise, if the core were constructed of solid iron, would attain considerable and even dangerous proportions.

Disc Armature Cores.—The cores of all large armatures of the ring and drum types are as a rule built up of iron discs; when small, however, they are frequently constructed of iron wire. The discs are stamped out of thin sheet-iron of about $\frac{1}{32}$ of an inch in thickness, with a hole in the centre of each disc sufficiently large to accommodate the shaft and driving spokes, and also the conductors in the case of ring armatures. In most cases notches or keyways are stamped on the inner periphery of

the discs (as in Fig. 31), to fit over the driving spokes, or over feathers running along the length of the shaft. These thin discs are then separated by some insulating material, and clamped between two thicker end discs or flanges so as to form a solid cylinder or drum. In this mode of construction the iron core, whilst carrying out its primary function of conducting the lines of force from pole to pole of the field magnet, interposes such considerable resistance in the path of the eddy currents as to effectually prevent these latter attaining any appreciable strength.

FIG. 31.

Toothed Cores.—Ring and drum cores are now very frequently constructed with deep slots or channels in the outer periphery in which the conductors are wound. To form these slots, the core discs are stamped out with projections or teeth arranged at regular intervals around the periphery (Fig. 32), and clamped together so that continuous ridges and interspaces are formed running along the length of the core. It is the usual practice, previous to fitting in the conductors, to mill out these slots, so that a smooth surface is formed to which insulating material, in the form of slips of mica, may be applied. At one time

FIG. 32.

this form of core was rarely employed, owing to difficulties arising from the tendency—occasioned by its use—for eddy currents to be produced in the pole pieces of the field magnets, and in the excessive lead of brushes and sparking at the commutator, and also in a peculiar hum, due to rapid reversals of magnetism in the teeth, being produced. These disadvantages have now, however, been almost completely overcome by suitably designing the shape and the number of the teeth, and suitably proportioning the air space, and as this type of core has enormous advantages in the way of the reduction of the magnetic reluctance of the air gap, and in the protection and positive mechanical driving of the conductors, it is now almost universally employed in dynamos of the better class of construction.

Insulation of Core Discs.—In order to prevent the circulation of any considerable eddy currents within the core, the core discs are electrically insulated from one another. Owing, however, to the very low E. M. F. of the currents, the insulation required is very slight; some manufacturers separate each disc by a paper or mica disc of similar form to the iron disc; others merely varnish the discs with shellac or other varnish, and this slight insulation is found to be quite effective in the prevention of dangerous eddy currents.

Driving Spokes and Spiders.—In most armatures the driving spoke or spider wheel serves a double purpose, (*a*) to firmly clamp the core discs together so as to form a solid core; (*b*) to firmly fix the core to the shaft. The method generally followed in clamping and holding ring armature cores is illustrated in Fig. 33. The spiders or stars are of gun-metal, and

are two in number, each having four arms or spokes, with end projections against which the thicker end flanges fit. The core discs are stamped with four notches or slots on their inner periphery, and the

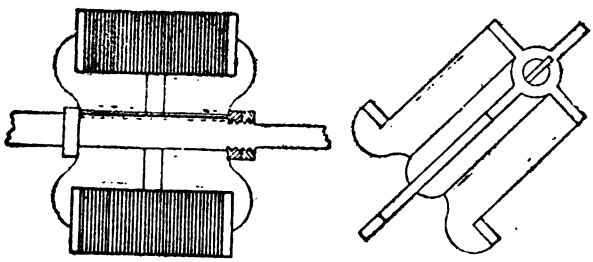


FIG. 33.

arms of the spiders engage in these and prevent the discs turning. The spiders fit over the shaft, and are prevented from turning thereon by feathers. One of the spiders fits against a shoulder turned upon the

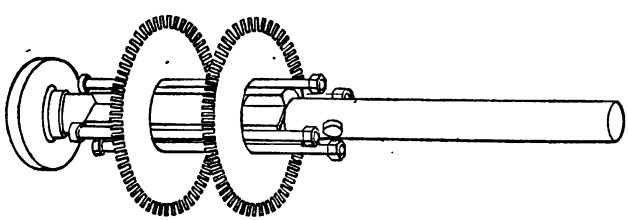


FIG. 34.

shaft, and the core discs are strongly compressed between this and the spider by means of lock-nuts turning upon threads cut upon the shaft. All well-constructed ring armatures are now provided with these driving spokes or spiders; drum armatures

are, however, generally built up on the modified form shown in Fig. 34. In this method ribs are formed either solid with the shaft, or feathers are fitted into groves milled along the length of the same. Semi-circular grooves are planed in the projecting edges of the ribs, in which rest long clamping bolts, and the discs being suitably notched, slide over these bolts, and are tightly clamped together between two thicker end plates, by means of the nuts on the ends of the bolts. Spaces being thus left between the shaft and the core, the air has free access to the interior of the armature, and the rotation of the latter causing a continual circulation to take place through the core and windings, the working temperature of the whole machine is much reduced.

Ventilation of Armatures. — The cores of all armatures are liable to become heated through the generation of eddy currents, the transmission of the heat from the conductors, and other causes. In small armatures no special means are taken to get rid of this heat, the relatively large amount of surface exposed, and the high initial velocity of such armatures, being found sufficient to prevent any dangerous rise of temperature. In the case of large armatures, however, some means of ventilation must be adopted, otherwise the armature will heat up to a dangerous extent. The method generally followed in such armatures is to cause air currents to circulate among the conductors and in the interior of the core. For this purpose the conductors are wound with air spaces between them, and cooling gaps are frequently left at intervals between the core discs. When the core discs are fixed direct on to the shaft, they are fre-

quently punched with holes, so that when assembled upon the shaft continuous ventilating apertures are formed in the core, through which the air circulates and carries off any excess heat.

Drivers.—When a current is flowing in the conductors of an armature revolving in a magnetic field, the magnetic attractions and repulsions set up have a tendency to displace the conductors and drag them out of their places around the core. Means must therefore be taken to resist this injurious action, and to fix the conductors immovably to the core. In small armatures, where the displacing forces are relatively very small, simple friction is generally relied on to effect the purpose, the grip of the conductors upon the core, reinforced by the pressure of the binding wires, being found quite sufficient to hold the conductors in their places. In the case of large armatures, however, where the displacing force upon each conductor may amount to many pounds, some more positive means of driving the conductors must be adopted; with this object the cores of such armatures are generally provided with *drivers* of metal or other substance. These drivers are arranged and fixed to the core in a variety of ways; in some cases they consist of steel or other metal pins insulated with vulcanised fibre, and screwed or driven into the core for a certain distance, so that they stand up level with the conductors; or strips of wood or fibre are arranged longitudinally along the surface of the core, being screwed to the latter, or let into grooves milled or planed in the surface of the core. Either of these forms of drivers, in conjunction with the binding wires, forms a most effective means of

driving the conductors, and entirely prevent any slip of the latter over the core.

Conductors.—In all practical armatures the conductors are invariably of copper, although iron has been suggested for the purpose at different times. For small currents they are generally of circular section, and wound in two or more layers upon the surface of the core; but for heavy currents they are always of rectangular or trapezoidal section, in order to economise the space around the periphery of the armature to the greatest extent. In both cases they are insulated with silk, or a double layer of cotton braided on and varnished with shellac, rubber, or other suitable insulating varnish.

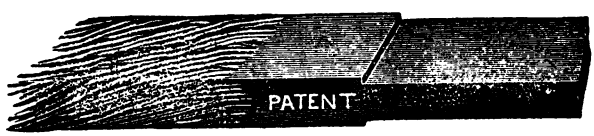


FIG. 35.

Laminated Conductors.—When the cross sectional area of the active conductors of an armature exceed a certain limit, there is great liability for eddy currents to be generated within them. To prevent this occurring, many makers employ laminated conductors, or conductors formed of stranded copper wires. In Messrs Crompton's patent stranded armature conductors, the separate strands are varnished or oxidised, or otherwise lightly insulated from each other, and then compressed into a bar of rectangular or trapezoidal section, as shown in Fig. 35. These stranded armature bars are very effectual in

the prevention of eddy currents and the accompanying waste of energy, Messrs Crompton having found that by their use in large armatures the efficiency of the dynamos is increased as much as 3 or 4 per cent.

Wire Wound Armatures.—It is the common practice in wire wound armatures of the ordinary pattern to wind the conductors, in separate convolutions around the core, by hand, beating them into place with wooden mallets and wedges. As thus wound, the coils are immovably fixed to the core, and as this system necessarily involves the passage of the whole of the coils over each end of the core, it becomes an extremely difficult matter to effect any repairs to the armature, for the reason that it is practically impossible to prevent coils already fixed in place being overlapped by other coils subsequently wound. Hence, if at any time it may become necessary to rewind a coil, as may happen through the insulation of a coil being damaged when the machine is completed and at work, or even during construction, the removal of the overlapping coils, and frequently the greater portion of the armature winding is involved in the repair of a single coil. To obviate this, in machines of the best and most modern construction, a patented system of winding is adopted, by means of which each individual coil is at all times entirely separate and independent of the remainder of the winding. To enable this to be effected, each coil previous to being fixed upon the armature core is wound to the exact shape required, upon a "former." This latter is simply an appliance formed of wood or metal, of such shape that the coils, when wound upon

it, take the exact form required for their symmetrical arrangement on the core. The whole of the coils required for a particular size of armature being formed upon an appliance of this description, their interchangeability is at all times assured. A method of arranging the coils upon this principle, adopted by the British Thomson-Houston Co. in the construction of their machines, is illustrated in Fig. 36. This represents a single armature coil, which, after being

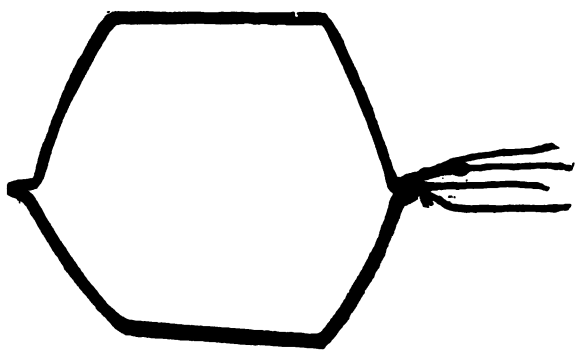


FIG. 36.

wound upon a "former" of the type described above, is insulated with tape, varnished, and tested, previous to being fixed upon the core. The best form of core, suited to this particular type of coil, is shown in Fig. 37. As will be observed, it is of the slotted drum pattern. It differs, however, from most armatures of this description, in that the clamping spiders which hold the core discs together are extended at either end of the drum in the form of wide cylindrical flanges. The purpose of these flanges is to receive the inactive

portions of the windings, which in this method take the form of a cylindrical or "barrel" winding, spanning an arc of the circumference of the core, in place of passing direct across a diameter at each end of the drum, as in the ordinary method. The active portions of the windings are embedded in the slots, running along the periphery of the core, the coils being insulated from the latter by means of strips of mica, as shown in Fig. 38, which represents an armature partly wound with coils of this description. The whole of the coils, including the portions arranged upon the flanges and in the slots, are, when fitted in place, firmly bound down by means of binding wires, so that the whole winding forms a most compact and practically solid structure. A complete armature as thus constructed is illustrated in Fig. 39. This system forms a very convenient method in practical work, as, owing to the coils being interchangeable, it is possible to keep a stock, ready to be fixed in place,

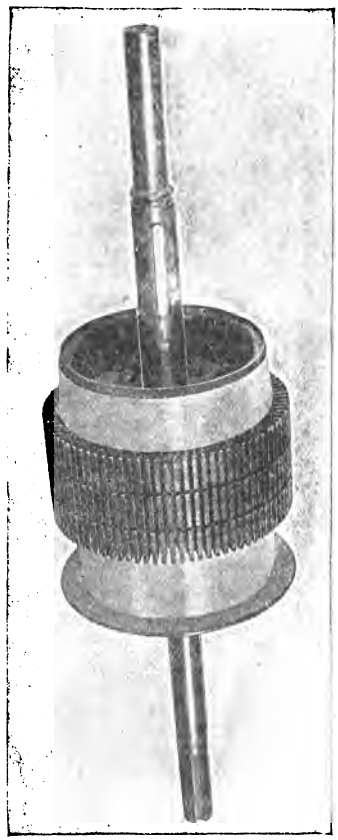


FIG. 37.

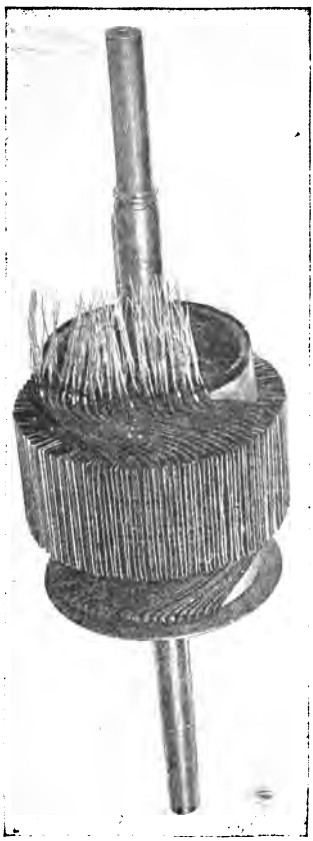


FIG. 38.

FIG. 39.

if at any time it becomes necessary to remove a coil through a "burn out" or other cause.

A large size armature, having windings of the cylindrical barrel type, as manufactured by the Lancashire Dynamo and Motor Co., is illustrated in Fig. 40. As

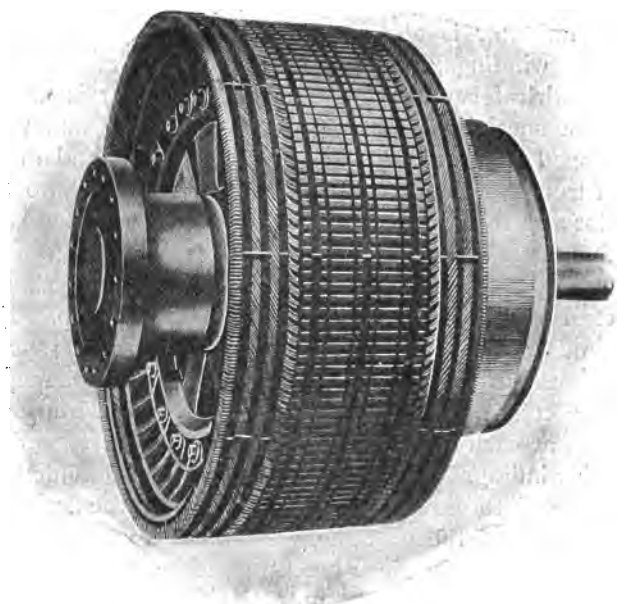


FIG. 40.

will be seen it is intended for direct coupling to the engine shaft, and is fitted complete with commutator. In building up this armature, the core is formed of thin varnished plates provided with slots to receive

the windings, and the core is further ventilated by suitable internal air ducts in the core to ensure cool running. The core plates are securely keyed to a cast-iron sleeve, which extends to the bearings on one side and is formed into a coupling on the other for direct coupling to the engine shaft, thus enormously strengthening the shaft, and eliminating any strain on the keys in case of short-circuiting. The commutator is also carried on this cast-iron sleeve. The windings, as already mentioned, are of the cylindrical barrel type. Each coil or bar is wound on a special former, afterwards taped up and then dipped in a special insulating compound, and dried. A trough of prepared insulation is next put into the slot and the coil or bar slipped into position. After they are all in place, wood strips are driven into the tops of the slots, which are specially dove-tailed, and steel bands wound tightly on and soldered up. The bands are carried in recesses in the core, so that in case the armature touches the fields it is not damaged. The coils or bars are provided with a cast-iron support at each end to prevent oil or dust getting into the windings. Double oil throwers are provided on the shaft to prevent any oil leaking into the armature or frame of the machine. On parallel wound armatures equalising rings are fitted, these rings automatically equalising the potential difference between brushes.

Bar Connector Armatures.—Previous to the introduction of the cylindrical barrel and other types of former wound coil armatures, *bar connectors* were frequently used in large size armatures. These connectors, as their name implies, are used for the

purpose of connecting the conductors situated at opposite sides of the core together. They consist of flexible strips or stampings of thin sheet-copper, insulated with tape or other suitable material, and arranged at either ends of the core. They take a variety of forms or shapes, but the arrangement due to Hopkinson has been most extensively used in practice. Dr Hopkinson's method of arranging the connectors is shown in Fig. 41. The conductors of the armature are rectangular in section, laminated,

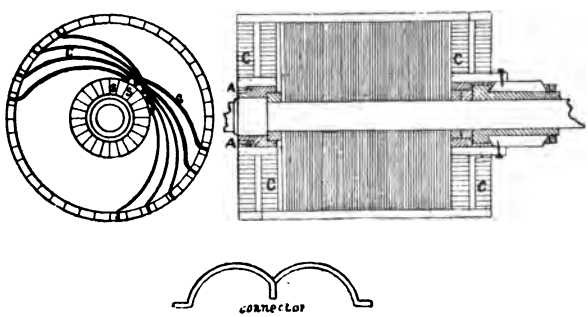


FIG. 41.

and project over the ends of the core for a longer or shorter distance alternately, as shown in the side view, Fig. 41. Two commutator-like structures A A, consisting of a number of copper segments S S, insulated from each other and fixed upon a wooden drum, are arranged at either end of the core, and into saw-cuts in each of these segments are soldered two thin strips of copper C C, insulated with tape. These thin copper strips are bent in opposite directions (as shown in end view, Fig. 41), and their ends are soldered into

the long and short armature conductors situated at approximately opposite ends of a diameter of the core, as shown in the end view of Fig. 41. At the commutator end of the armature the copper segments are continued outwards, and connected to the commutator segments, as represented in the side view, Fig. 41. While these connectors answer their purpose in an admirable manner, the use of the barrel type of winding is much to be preferred in any armature.

Binding Wires.—The conductors of an armature, in addition to being subjected to the peripheral drag exerted by the magnetic field, are also subjected to the influence of the centrifugal force developed by the rotation of the armature. As most armatures are driven at a high peripheral speed, this force is often considerable; therefore, in order to counteract the tendency of the conductors to be driven off by the action of this force, they are bound down to the core by means of bands of binding wires. These binding wires are usually of steel, hard brass, or phosphor-bronze, wound under tension upon bands of vulcanised fibre and mica, fixed upon the periphery of the armature, and soldered at intervals to obviate flying asunder.

The Commutator.—The commutator as a rule is built up separately from the armature, and consists of a number of segmental bars of brass, copper, or phosphor-bronze, insulated from each other, and fixed in a clamping sleeve which slides over and is made fast to the shaft.

Construction of Commutators.—The construction of commutators suitable for small-sized machines

is illustrated by the example given in Fig. 42. Two views of this commutator are given, the upper half in each case being shown in section. The segments B are of hard drawn copper, insulated from each other by slips of mica, M. Square clamping notches, N, are turned in the ends of the assembled bars, into which fit grooved rings of hard vulcanised fibre. These rings have a coned surface, and are cut into three segments so as to permit of slight contraction.

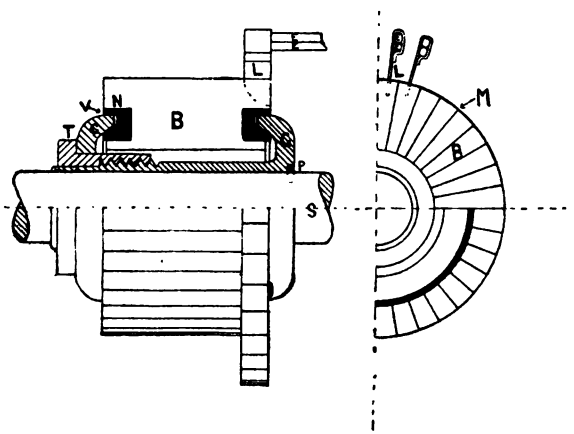


FIG. 42.

A gun-metal bush or sleeve, G, having a cone turned upon one end, slides over the shaft S, and is prevented from turning thereon by the pin P. A tubular nut, T, screws on to one end of the bush, and over this slides a loose coned collar, C. The two gun-metal cones fit into the grooves in the fibre rings, and when forced together by the screw-nut T on the end of the sleeve, bind the whole of the segments

firmly together. The electrical connection of the segments of the commutator to the coils of the armature is affected by means of the lugs L. These are made of thin strip copper, of a suitable length, to connect the ends of the armature coils to the segments of the commutator. A saw-cut is made in

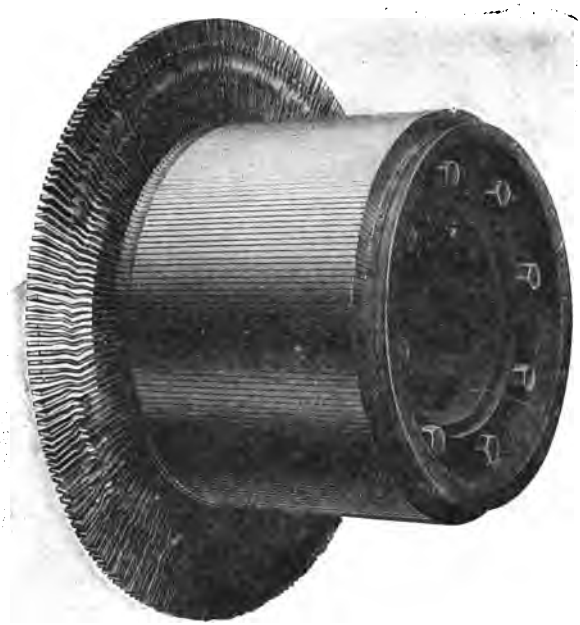


FIG. 43.

one end of each of the segments, and one end of the lug is soldered or sweated into this, the other end being bent round and soldered to the projecting ends, E, of the armature coils, as represented in the sectional view of the commutator.

The construction of a large size commutator is illustrated in Fig. 43. The segments are of hard drawn copper insulated with mica, micanite being used for insulating the end rings. These end rings are divided into segments which are drawn together by special steel rings of wedge-shaped section. In this way the bars are held down with great pressure, but are left free to expand longitudinally, and with this method of construction it is almost impossible for a bar or segment to be knocked down below the level of the others with a hammer.

Brushes.—The brushes bear upon the commutator, and make sliding contact with the armature and working circuits. It is needful that they should have a certain amount of flexibility, in order that they may accommodate themselves to any little inequality which may occur upon the surface of the commutator, and also to avoid cutting or scoring the latter, and at the same time be divided or laminated in such a direction that the tendency to short-circuit adjacent bars of the commutator as they pass over them is reduced to a minimum ; with these objects, they are usually made of copper or brass gauze, wire, or flexible strip.

Gauze Brushes.—This type of brush is now very extensively used, owing to its great flexibility and soft and yielding nature, resulting in decreased wear of the commutator, and also in the comparative absence of sparking consequent to the use of the fine wires composing the gauze. It is made up of a sheet of copper gauze, folded round several times, with the wires running in an oblique direction, so as to form a solid, flat strip of from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch in thickness, as shown at A, Fig. 44, the thickness increasing with

the volume of the current to be collected. The object of folding the gauze up with the wires running in an oblique direction is to prevent the ends of the brushes fraying or threading out, which would be the case if the gauze was folded up in any other manner.

Wire Brushes.—The latest form of this brush is

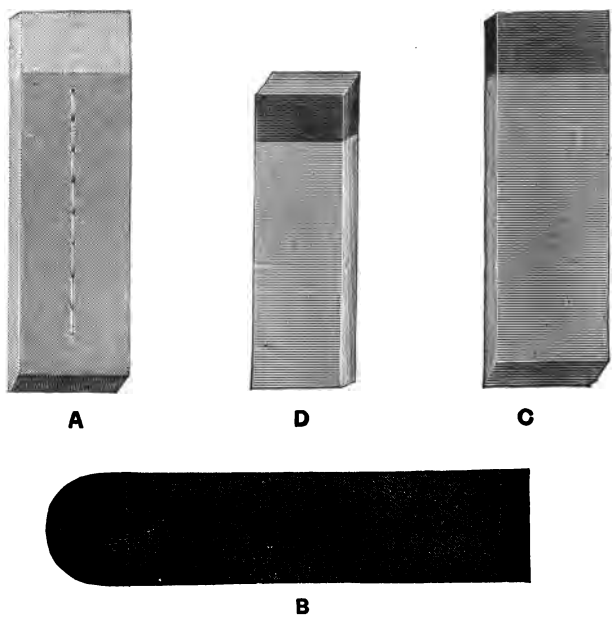


FIG. 44.

illustrated in B, Fig. 44. It is composed of a large number of fine copper wires, No. 36 S.W.G., folded into a flat bundle, and finally covered with a sheet of wire gauze. It possesses the same qualities as the

gauze brush, of which it is practically only another form.

Strip Brush.—This is probably the simplest form of brush, but it is not very extensively used owing to its lack of flexibility. It consists of a number of strips of copper or brass, laid one upon the other and soldered at one end, as in C, Fig. 44.

Carbon Brushes.—When metallic brushes are used upon the commutators of high tension machines, they frequently give rise to excessive sparking, and also heating of the armature, the metallic dust given off appearing to lodge between the segments of the commutator, thus partially short-circuiting the armature. To obviate this, carbon brushes are now extensively used on such dynamos, this substance being found very effectual in the prevention of sparking. The brushes are usually in the form of oblong blocks (D, Fig. 44) placed "butt" end on the commutator, and fed forward as they wear away by means of a spring holder. This gives the advantage that if the machine is run backwards, either through accident or design, there is no danger of the brush being damaged by causing it to trip on the edge of some commutator bar, should the mica insulation be somewhat below the general level of the surface of the commutator, as sometimes happens. The general introduction of carbon brushes has been due principally to the use of the higher voltage machines, of 200 volts and upwards, rendered necessary by the adoption of extended systems of distribution for electric light and power purposes. On these machines they are found to be highly satisfactory, producing a better surface on the commutator and reducing the amount of wear

considerably, while the collection of carbon dust is far less objectionable about a commutator than that of copper dust, being less likely to cause short-circuiting. The principal advantage of the carbon brush, however, is in the reduction of sparking at the commutator of these machines. Owing to the high specific resistance of carbon, these brushes tend to keep the current down when commutator bars are short-circuited by coming under the brush, and consequently there is little or no sparking when a bar breaks circuit with the brush. This advantage, however, becomes less apparent in machines intended for lower voltages, as the potential difference between individual bars of the commutator is then usually very small, and in such machines there should usually be little sparking even with copper brushes having high conductivity, provided they are of suitable pattern. The higher the voltage the more necessary are carbon brushes, while for very low voltage work, such as machines intended for electro-plating and metallurgical processes, they are quite unsuitable.

Brush-Holders.—In order to secure sparkless collection of the current, and to prevent undue wear of the commutator, it is needful that the pressure of the brushes upon the latter should be capable of being adjusted to meet requirements; it is also needful that they should be capable of being fed forward as required, as they wear away, and that they be furnished with a movement to permit of the brushes being raised from contact with the commutator when necessary. Each maker has his own particular arrangement for giving these essential motions to the brushes, and, as may be conceived, they frequently

differ widely. The requirements of a good brush-holder, adapted for metallic brushes, are met in a very efficient manner in the brush-holder illustrated in Fig. 45. A pair of the brush-holders mounted complete on the arms of the rocker is shown in Fig. 46. The holder consists of two parts—the tail-piece T fixed immovably to the arm of the brush rocker by means of the small set-screw D, and the movable brush clamp A capable of revolving through a small angle on the fixed tail-piece. Contact pressure of the brush is produced by the laminated plate-spring S (shown more clearly in Fig. 46), the tension of which is adjusted by means of a regulating screw and lock-nut R. The brush is held up from contact with the commutator by means of the hold-off catch C, composed of a vulcanised fibre cam turning on a pivot. The brush can be fed forward in the holder, or drawn back and adjusted, while the machine

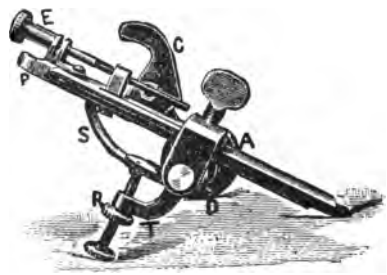


FIG. 45.

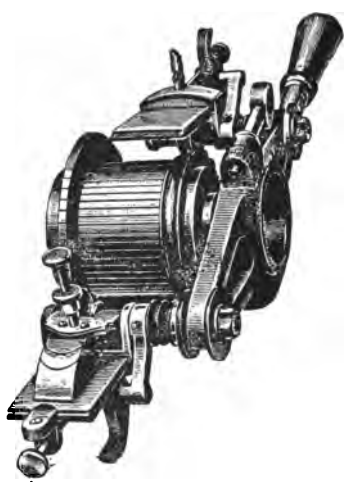


FIG. 46.

is running, by unscrewing the clamping-screw H and adjusting the regulating-screw E. The brush is connected to the terminals of the machine by means of a flexible "lead," bolted to the point P of the holder. In all well-designed dynamos not less than two brushes are used on each side of the commutator; this allows of either brush being removed, and examined and trimmed, while the machine is running. It also allows of the brushes being adjusted upon the commutator independently of each other,

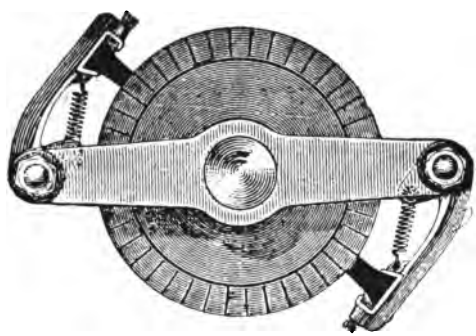


FIG. 47.

any uneven wear of the commutator being thus prevented, and better contact made.

Carbon Brush Holders.—Carbon brushes being almost invariably fitted for use "butt" end on the commutator, require a different pattern brush-holder to that necessary for metallic brushes, which are usually worked with their ends placed more or less at a tangent to the commutator. Owing to there being no danger of the brushes being destroyed if the commutator takes a reverse movement, the construction of the carbon brush holder is of an essentially

simpler character to that required for metallic brushes. A carbon brush-holder of a simple and efficient kind is illustrated in Fig. 47. The carbon brush in this instance is of a wedge-shaped pattern, and is slipped into the metal brush-holder and firmly fixed in place by means of a small pinching screw. The brush is pressed upon the commutator by means of a spiral spring.

Brush Rockers.—As previously mentioned, when

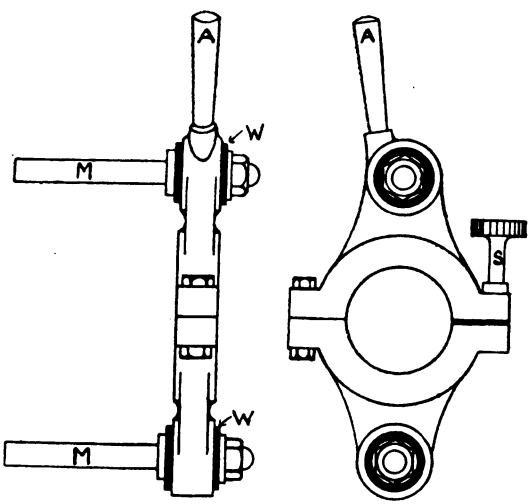


FIG. 48.

a dynamo is working, the neutral points, or the points upon the commutator where sparkless collection of the current can be made, vary in position as the load upon the dynamos varies, moving round in the direction of rotation as the load increases, and *vice versa*. It is necessary therefore, in order to avoid sparking,

to shift the brushes bodily upon the commutator from time to time, without in any way altering the adjustments of the brush-holder springs or breaking the working circuit. To enable this to be effected the brushes with their holders are, in ordinary bi-polar dynamos, usually fixed upon a "rocker" or "yoke." Fig. 48 illustrates the form of rocker commonly used. It is of cast-iron or gun-metal, made in two pieces and bolted together. The central aperture is turned out to fit into a groove turned in one end of the bearing next to the commutator, and the rocker, when rotated by means of the handle A into the correct position for the brushes upon the commutator, is clamped in position by the clamping-screw S. Through holes at opposite ends of the bar project two gun-metal spindles, M M, upon which the brush-holders are firmly fixed by the set-screws (D, Fig. 45). These spindles are entirely insulated from the rocker bar and from each other by the vulcanised fibre bushes and washers W W.

Brush Rings.—In all large machines it is now the common practice to provide a hand wheel and self-locking worm gearing, in place of the handle and clamping screw shown in Fig. 48, for the purpose of rotating the rocker; the great weight of the brushes and rocker, and consequent resistance to motion in such machines preventing the brushes being accurately adjusted by hand alone. A brush ring of this description, adapted to carry a large number of brushes and holders is shown in Fig. 49. This brush ring is intended for use with the large multipolar armature described on p. 73. It consists of a strong cast-iron ring carried from the magnet frame and mounted con-

centrically with the commutator, arranged to rotate so that the position of all the brushes may be simultaneously adjusted by means of the hand wheel and screw gear shown in the illustration.

FIG. 49.

Self-Oiling Bearings.—These are now one of the essential adjuncts to all modern electrical machinery. The lubrication is effected by means of one or other of the automatic revolving ring methods, of which

Fig. 50 represents a good example. In the particular pattern illustrated, the plummer block or bearing is cast hollow, and forms a reservoir for the oil which is used for lubricating the shaft. The shaft revolves in gun-metal bushes which are fitted into spherical seatings, so as to be self-aligning. The bushes are slotted transversely to half their diameter at either side of the spherical seat, so that grooves are formed into which fit two metal rings of a larger diameter than the shaft. When the shaft is in place, these rings rest upon and therefore revolve with it, and as the lower edges of the rings dip into the oil, a continuous stream of oil is carried up to the shaft, and being there distributed by means of suitable channels or grooves cut in the bushes over the entire journals, a continual circulation of lubricant is automatically kept up so long as the shaft revolves. It is the custom with some makers to fill the lower portion of the pedestal with water previous to the introduction of the oil, the object of this being to form a kind of filter for the lubricant, which, floating on the water, any grit or other foreign matter removed from the bearings by the action of the lubricant, has a tendency to sink and be drawn off with the water, the oil being used over and over again until its lubricating properties disappear.

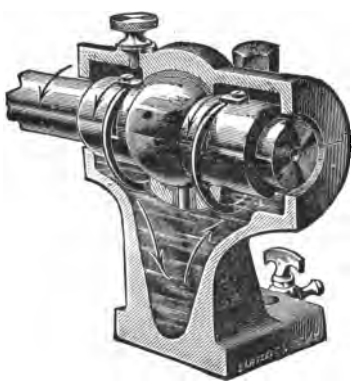


FIG. 50.

CHAPTER VI.

FIELD MAGNETS.

THE field magnet, the function of which is to produce an intense magnetic field within which the armature revolves, may be either a permanent magnet or an electro magnet. Electro magnets, however, possess such a number of important advantages over permanent magnets, that they are now invariably used in all machines intended for practical work. The chiefest advantages of the electro magnet, as compared with the permanent magnet, lies in the power of regulating the strength of the magnetic field produced by the former, by suitably adjusting the strength of the magnetising current flowing through its coils, and also in the greater magnetic effect obtained, weight for weight, from the electro magnet over the permanent magnet.

Excitation of Field Magnets.—The field magnets of a dynamo may be excited, either by the current furnished by an independent dynamo or battery, in which case the machine is said to be "*separately excited*," or by the current generated in the armature of the machine of which the field magnet forms part, when the machine is said to be *self-excited.*

Self-Excitation.—The latter type of machine depends for its action upon the presence of residual magnetism in its field magnet. Owing to this residual magnetism, a weak magnetic field is always present between the pole pieces of a field magnet; hence, when the armature is rotated in the armature chamber, its conductors cut the lines of force contained in this magnetic field, and a small E.M.F. is set up in the armature in consequence. The ends of the magnetising coils being suitably connected to the brushes, if these latter are in contact with the commutator, and a closed circuit through the field magnet windings is formed, this small E.M.F. immediately sends a minute current through the exciting coils; this immediately increases the strength of the magnetic field, and as a consequence an increased E. M. F. is induced in the armature. This results in a stronger current being sent through the exciting coils, and the increase of magnetism which follows results in an increased E.M.F. in the armature. Thus the process goes on, until eventually, for a given speed of rotation of the armature, the E.M.F. reaches a maximum value, beyond which it will not increase without a further increase in the speed of rotation; the exciting current has then arrived at a constant value, and the magnetisation of the machine will remain at a constant strength, and maintain the E. M. F. so long as the armature rotates at its normal speed. If the armature ceases to revolve, the field magnets will of course be deprived of their exciting current, and will therefore lose their magnetism; the iron will, however, retain a sufficient amount of residual magnetism to again start the

process when the machine is again started. In most cases an appreciable time elapses before the voltage arrives at its maximum value: in small dynamos, a few seconds generally suffices to fully excite the machine; in the case of large shunt dynamos, it may require a minute, or even five minutes in exceptional cases.

Classification of Dynamos. — The manner in which the coils of the field magnets are connected to the armatures of self-exciting machines gives rise to the following classification:—

(1) *Series Wound Dynamos.* In which the coils of the field magnet are connected in series with the armature and external circuit.

(2) *Shunt Wound Dynamos.* In which the coils of the field magnet form a shunt to the armature and external circuits, and, being composed of many turns of fine wire, absorb only a fraction of the total current.

(3) *Compound Wound Dynamos.* Wherein two coils are wound upon the field magnets, arranged in a combination of shunt and series: one coil being wound with a large number of turns of fine wire, and connected as a shunt to the armature; the other being composed of a few turns of thick wire, and connected in series with the armature.

(4) *Over-Compound Wound Dynamos.* The series coils of which are composed of a relatively large number of turns in comparison with ordinary compound wound dynamos.

(5) *Alternative Compound Wound Dynamos.* Having the coils arranged as in an ordinary compound dynamo, but with the addition of a switch to the

series coils, by means of which the coils may be short-circuited or cut out of circuit entirely, thus converting the machine into a simple shunt dynamo.

Separately Excited Dynamos. — This type of machine is not so extensively used as the self-exciting type, owing principally to the fact that an

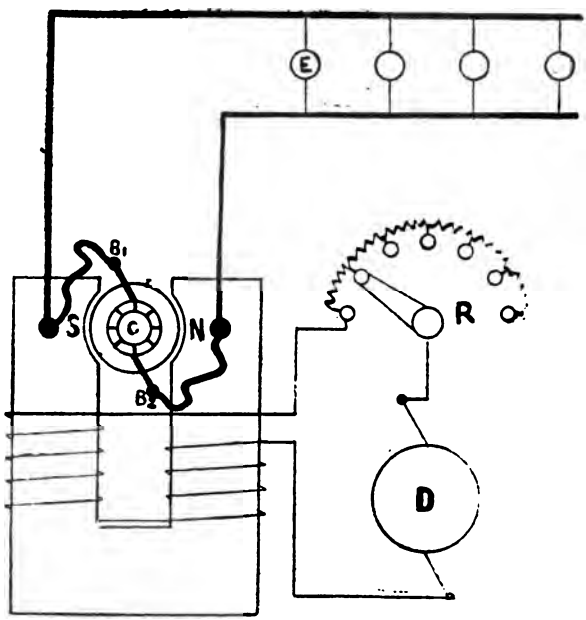


FIG. 51.

independent dynamo or battery is necessary for exciting its field magnet. It finds its chiefest application in the electric transmission of power, and in charging accumulators, and in all cases where a high E. M. F. is required with a varying current. The connections of this dynamo are shown in Fig. 51,

where N S are the poles of an electro magnet, which is excited by the current generated by the independent dynamo or battery D. The armature A revolves in the space between the two pole pieces, and the two brushes B_1 B_2 press upon the commutator C, and convey the current generated in the armature to the external circuit E. The E. M. F. and output of the dynamo is usually regulated by varying the strength of the magnetising current (produced by the dynamo or battery D) flowing in the coils of the field magnet by means of the hand-regulator R.

Series Dynamos.—The manner in which the connections of the series wound dynamo are arranged is shown in Fig. 52. The coils of the field magnet are wound with a few turns of thick insulated wire, and being joined in series with the armature, the whole of the current generated in the latter passes direct through them, and thence to the external circuit. The current in passing through the coils of the field magnet energises the latter, and creates a magnetic field between the two poles N S, in which the armature revolves. A little consideration will show that the strength of this magnetic field, and therefore the E. M. F. of the machine, will vary in direct proportion to the current flowing in the external circuit, since the current flowing in the external circuit is also the magnetising current. If the external current is "open," no current will flow therein, and therefore the field magnets will be unexcited, and the only magnetic field will be that due to the residual magnetism of the field magnets; the E. M. F. of the machine will, therefore, be practically *nil*. In,

on the other hand, the external circuit is closed, so as to offer a minimum resistance, or "short circuited," the field magnet will be excited to the greatest extent, and the E. M. F., and current flowing in the external circuit will be approximately a maximum.

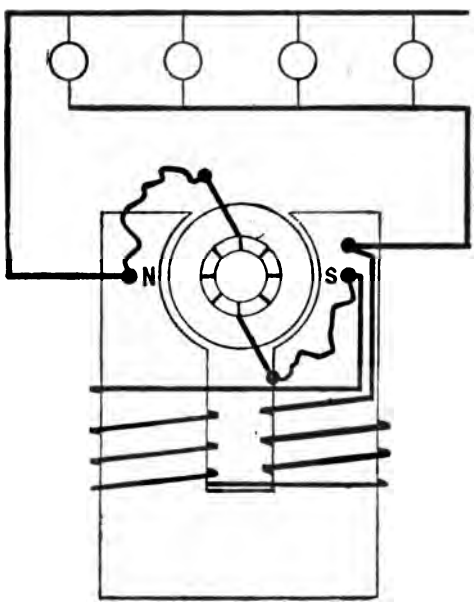


FIG 52.

Characteristic Curves.—The behaviour of series wound and other dynamos can best be studied graphically by means of "*characteristic curves.*" As Prof. S. P. Thompson remarks,* "the characteristic curve stands to the dynamo in a relation

* "Dynamo Electric Machinery," Spon, 1892.

very similar to that in which the indicator-diagram stands to the steam-engine. As the mechanical engineer by looking at the indicator-diagram of a steam-engine can at once form an idea of the qualities of the engine, so the electrical engineer by looking at the characteristic of the dynamo can judge of the qualities and performance of the dynamo." The shape or form of the characteristic

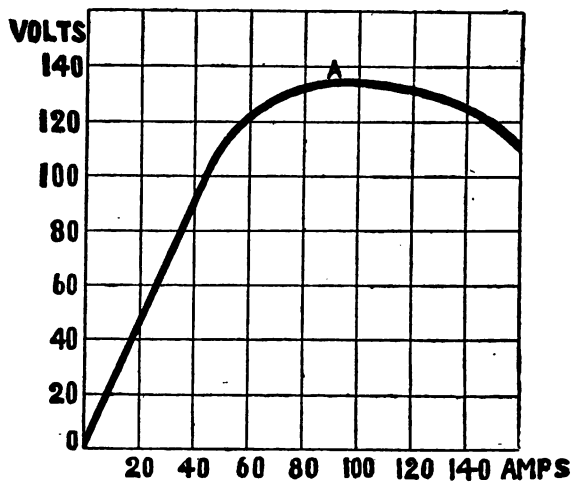


FIG. 53.

curve differs, of course, with the type of dynamo whose qualities it represents, the form of the characteristic of a series dynamo being entirely different from that of a shunt or compound wound machine. The characteristic of a series dynamo is given in Fig. 53. The abscissæ measured horizontally represent the number of amperes flowing in the circuit; and the ordinates, shown vertically, the corresponding

value of the terminal E. M. F.,—the armature rotating at a constant speed. It will be noticed that the curve does not begin exactly at the point O, but a little way up the vertical line; this indicates the existence of a small E. M. F. before current is taken from the machine, and is due to the residual magnetism of the field magnets. As current is taken from the machine, the magnetisation of the field magnets increases at first, very rapidly with the current; and therefore the electro-motive force increases also, giving the first portion of the curve. After a time, however, the cores of the field magnet become saturated; the curve then attains a maximum height, at A; and as more current is taken from the armature, the de-magnetising action of the latter, and the fall of pressure over the resistances of the machine, increase so rapidly, that the E. M. F. at the terminals of the machine is decreased, as indicated by the curve bending downwards. Series wound dynamos are chiefly used for lighting arc lamps in series, and for the electric transmission of power over long distances, and for other purposes where a high potential is required.

Shunt Wound Dynamos.—The shunt wound dynamo differs from the series wound machine, in that an independent circuit is used for exciting its field magnet. This circuit is composed of a large number of turns of fine insulated copper wire, which are wound round the field magnet and connected to the brushes, so as to form a shunt or "by pass" to the brushes and external circuit. Fig. 54 shows the connections of the shunt wound dynamo, from which it will be seen that two paths are presented to the current as it leaves the armature, between which

it divides in the inverse ratio of the resistance; whilst one part of the current flows through the magnetising coils, the other portion flows through the external circuit. In all well-designed shunt dynamos, the resistance of the shunt circuit is always very great, as compared with the resistance

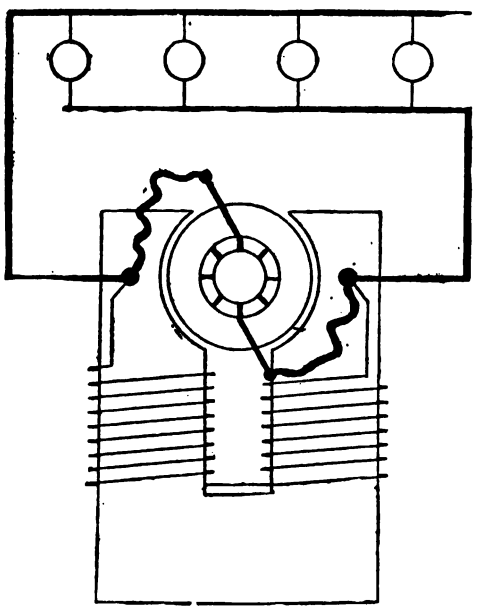


FIG. 54.

of the armature and external circuit, and the strength of the current flowing in the shunt coils rarely exceeds 12 amperes in even the largest machines.

Characteristic of Shunt Dynamo.—The general form of the characteristic curve obtained from a shunt wound dynamo is illustrated in Fig. 55. The

ordinates shown vertically represent the volts at the terminals of the machine, the abscissæ the amperes flowing in the external circuit, with the

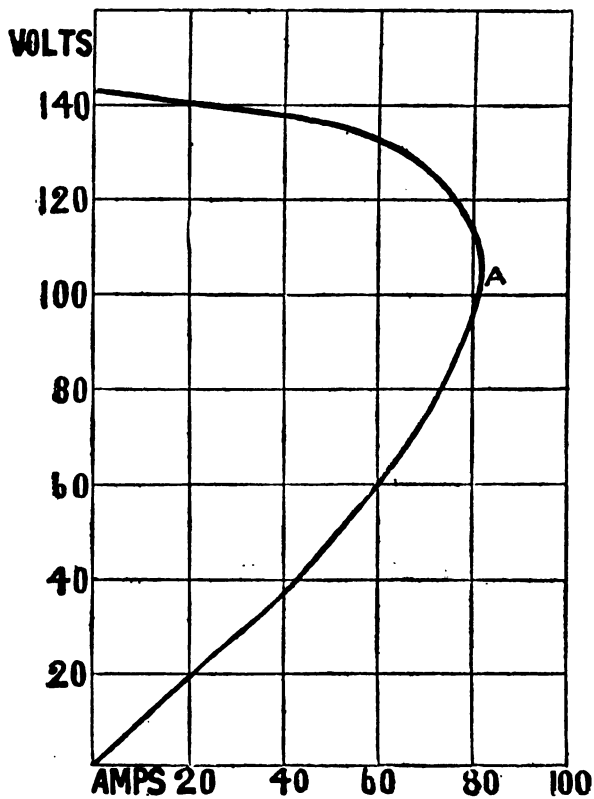


FIG. 55.

armature running at a constant speed. Starting with the external circuit open, the only current flowing is that in the shunt coils of the field

magnet, which latter is consequently magnetised to the greatest extent, and therefore the E. M. F. at the terminals of the machine is at a maximum value. When the external circuit is closed, as current is taken from the armature, the loss of volts over the resistance of the latter increases as more and more current is taken from the machine. Hence the pressure at the brushes is reduced, and this resulting in a decrease of the magnetising current, the curve begins to fall gradually downwards, until when the point A is reached the voltage has been so far reduced that the machine commences to de-magnetise or "build down," and the voltage then runs down to zero. The shunt dynamo is therefore only capable of supplying a definite maximum current, beyond which, if the resistance of the external circuit is still further reduced, the machine will de-magnetise, and cease to generate current at all. The behaviour of the shunt dynamo is thus in many respects the reverse of the series wound machine: in the latter, the E. M. F. is greatest when the current flowing in the external circuit is a maximum; in the former, the E. M. F. is a minimum under like circumstances. Owing to its non-liability to reversal of polarity, the shunt wound dynamo is extensively used for charging accumulators, and for electrolytic and electro-metallurgical work, and also in central stations for the supply of electrical energy.

Compound Wound Dynamos.—In practice, electric lamps, motors, and other applications of electrical power, are constructed for a definite pressure and current, which must be maintained constant if the

appliances are to work efficiently. In incandescent lighting, where the lamps are arranged in parallel, a constant voltage must be maintained between the terminals of the lamps, no matter how few or how many are burning. Under such circumstances it will be evident that simple shunt or series wound

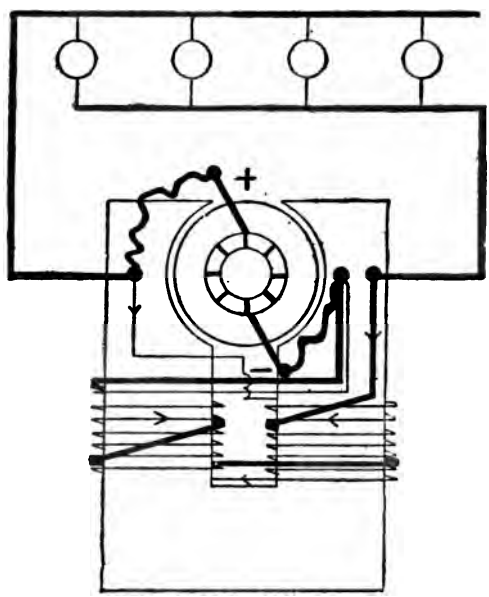


FIG. 56.

machines would be quite unsuitable, for the pressure would vary with every variation of the current as the lamps are switched into or out of circuit. For the purpose of automatically maintaining a constant pressure in incandescent lighting, the compound wound dynamo (Fig. 56) is now generally employed.

The field magnet of this dynamo is wound with two sets of coils, one set being connected in series, and the other set in parallel, with the armature and

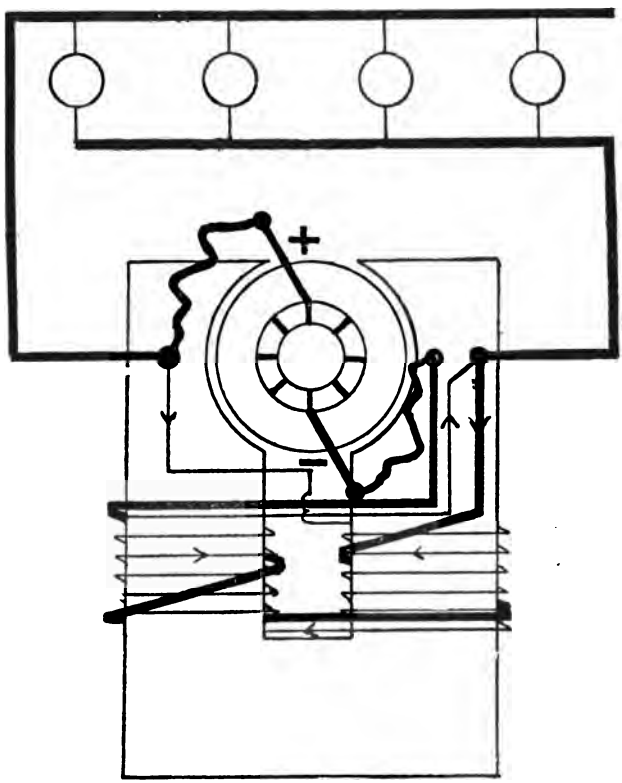


FIG. 57.

external circuits. The machine is in reality a combination of the shunt and series wound machines, and from what has been already stated regarding the behaviour of these types of dynamos, the action

of the compound dynamo will be apparent. When the external circuit is open, and no load is therefore on the dynamo, the shunt coil will maintain the E. M. F. at the terminals at the correct value; as the load increases, the fall of pressure at the terminals of the machine, due to the loss of volts over the armature resistances, and the reduced current in the shunt coils, will be compensated by the increase of induced E. M. F. in the armature, due to the increase of exciting power furnished by the series coils; and if the series and shunt coils are correctly proportioned, the E. M. F. at the terminals of the dynamo will be maintained constant throughout the entire range of the machine. This is, however, only true when the dynamo is run at the speed for which it was designed; at any other speed the windings will not compensate each other, and the voltage will not remain constant with a varying load.

Short and Long Shunt Compound Winding.— The method of connecting the coils of compound dynamos, represented in Fig. 56, in which the ends of the shunt coils are connected directly to the brushes, is known as the *short shunt winding*. Another method, shown in Fig. 57, in which the shunt is placed across the terminals, is known as the *long shunt winding*. Theoretically, the latter method is preferable, as being the most efficient; in practice, however, the gain is not very appreciable, and the former method is generally used.

Over-Compound Wound Dynamos. — In this class of machine the series coils are composed of a relatively large number of turns, in comparison with the ordinary compound winding, the effect of which is

to cause the voltage to rise with an increase of load, and thus compensate for the drop of pressure which occurs in long mains employed for lighting service, and also the heavy fall which frequently takes place in power circuits when a number of motors are started at one and the same time.

Owing to this property, this class of dynamo is universally employed in power stations in connection with electric traction systems and electric railways. As it is sometimes desirable to be able to adjust the degree of over-compounding, the series coils are, in most cases, provided with adjustable resistances placed in shunt with the latter so that the current passing through the coils may be regulated, and the voltage of the machine likewise.

Alternative Compound Winding.—In many cases, as in small country houses, it is frequently necessary to have a dynamo, capable of charging a storage battery during the day-time, and being used for driving the lamps direct during a certain portion of the evening. Under such circumstances this class of machine is most frequently used, the ordinary shunt dynamo not being capable of furnishing the necessary constancy of voltage, without attention being required to the shunt regulator while driving the lamps direct, while the ordinary compound dynamo is not suitable for charging storage batteries. To enable this type of machine to effect its purpose, the series coils are provided with a switch, which may either be fixed upon the machine itself or upon the switchboard, by means of which the series coils may be either short-circuited or cut out of circuit entirely while the machine is charging the storage battery, being again cut into circuit when the machine is required to drive the lamps direct.

Commutating Pole Winding.—It has been mentioned (p. 57) that the shifting of the neutral points or "lead" in dynamos is directly due to the distortion of the magnetic field by the armature reaction. As a consequence of this armature reaction, when current is being taken from the machine, the coils, being commutated and passing under the brushes at any given instant, are short circuited while actively cutting lines of force, and in consequence a large current is likely to be generated in these coils owing to their relatively small resistance if suitable means are not taken to prevent this occurring, resulting in heavy sparking at the brushes, if these are not moved into the neutral points as they shift about under varying loads. It is possible, by suitably designing the relative proportions of the armature and field magnet, to arrange that the armature shall have comparatively only a very small reaction at any output within its capacity, so that the distortion is insignificant. In machines correctly designed on this principle, the neutral points are practically constant over a large range of its capacity, and very little attention is needed to shift the brushes under varying loads. Where, however, the fluctuations of load are heavy, it becomes necessary to adopt some other means of preventing or neutralising the distortion of the field. Although various methods have been suggested for the purpose, the most successful, from a commercial point of view, has been the provision of "commutating" or compensating poles. These poles are small auxiliary poles placed between the main poles, their winding generally being in series with the armature. The compensating magnets set

up a special magnetic field in the neutral zone, the surface and strength of which is so designed as to ensure a commutating field sufficient to neutralise the E. M. F. acting in the coil undergoing commutation, so that sparkless commutation is secured under any load within, or even exceeding, the rated capacity

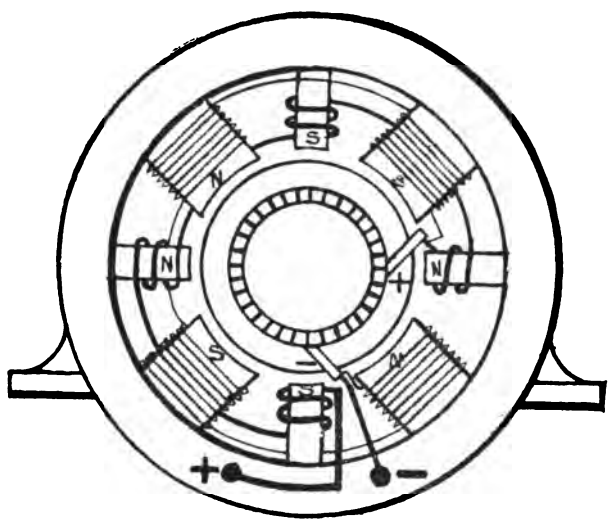


FIG. 58.

of the machine to the extent of 50 per cent. during short periods. The method of arranging the commutating poles in relation to the main magnets is illustrated diagrammatically in Fig. 58. The diagram shows a shunt wound machine fitted with commutating poles, which, as will be seen, are arranged in series with the armature.

CHAPTER VII.

FIELD MAGNETS IN PRACTICE.

WHILST the construction of the armatures of different dynamos may be said to be very much the same, differing in small details only, and being confined to two types, viz., the ring and drum respectively, the construction of the field magnets is capable of great variation, almost every manufacturer, until recently, having his own particular form and arrangement. This great variety in the form of the field magnets of different dynamos is due in a large measure to considerations of economy involved in the manufacture by different makers, and also, to a less extent, to the different conditions under which a machine is required to work. Within recent years, however, the iron-clad type of field magnet has proved so immeasurably superior to all other patterns that makers in all parts of the world are adopting it to an almost universal extent, and the great diversity of form which characterised the field magnet of former years has now given place to the simple ring type of American origin as illustrated on page 112.

Construction of Field Magnets.—Owing to difficulties of construction, and other considerations, field magnets are not in practice usually constructed out of a single piece of iron, but are usually built up of a combination of parts, and composed either wholly of

wrought or cast iron, or of a combination of both, or, according to the latest practice, they may be formed of cast steel of special quality and softness. To illustrate the various parts, and the distinctive terms applied to each, the construction of a typical field magnet, of simplest horse-shoe pattern, is represented in Fig. 59, from which it will be seen that it may be divided into five parts, viz.:—the two limbs or cores M M, upon which the exciting coils C are wound; the two end portions P P, called the "pole pieces," which are bored out so as to form the "armature chamber" within which the armature revolves; and the yoke Y, which serves to connect the two limbs together, and thus

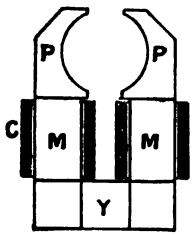


FIG. 59.

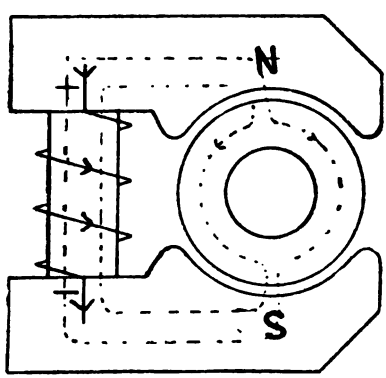


FIG. 60.

complete the magnetic circuit. The permeability of wrought-iron being very much greater than cast-iron, the portions M M of the field magnet, upon which the

exciting coils are wound, are frequently constructed of this material; these portions are also usually constructed of a circular section, and thus the amount of wire required for exciting the field magnet is economised to the utmost extent. The pole pieces

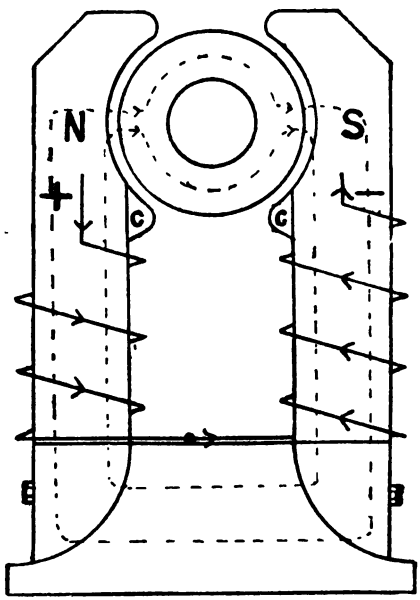


FIG. 61.

P P and the yoke Y are in many cases of cast-iron, bolted on to the wrought-iron limbs.

Forms of Field Magnets.—Although innumerable forms of field magnets have been devised, they can all be arranged into two groups, viz., those in which the poles are "salient," and those in which the poles are "consequent." A salient pole is the term

applied to poles which are produced at the ends of a bar of iron, in distinction to consequent poles, which are produced in a continuous ring of iron.

Salient Pole Field Magnets.—The salient pole form of field magnet, being least costly to construct, is most frequently met with in practice.

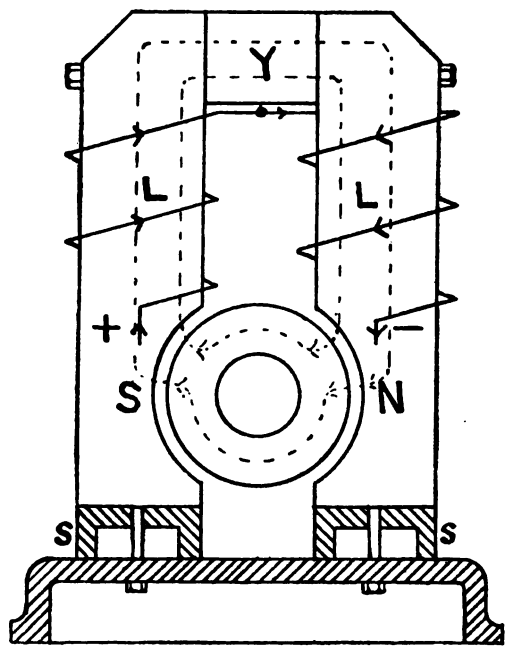


FIG. 62.

Fig. 60 shows its simplest form: in this arrangement only one magnetising coil is required, this being wound upon the yoke, which is usually of wrought-iron, let into and bolted to the cast-iron pole pieces N S. The paths and directions of the

lines of force, with the magnetising current flowing in the direction shown, is indicated by the dotted arrow heads and lines. Another form of field magnet which was formerly very extensively used, and in which two exciting coils are required, is shown in Fig. 61. In this type the limbs are usually of wrought-iron, of rectangular section, bolted to the bedplate of the machine, which therefore forms the yoke of the magnet. The magnetising coils are

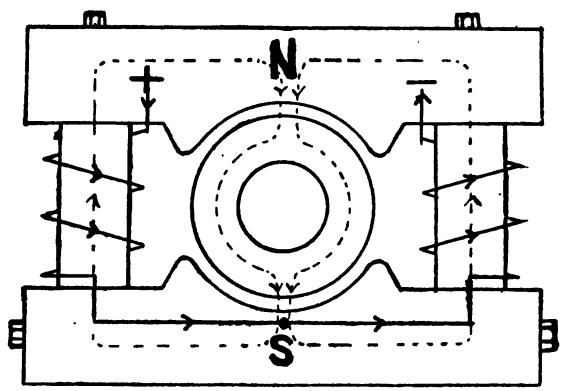


FIG. 63.

wound upon bobbins, which are slipped over the limbs, being held in place by the cast-iron "horns" C C, screwed on at the lower portion of the armature chamber. The form of field magnet illustrated in Fig. 61 is known as the "overtype"; when the armature is placed below the field coils and yoke, as represented in Fig. 62, the arrangement becomes the "undertype." This latter type was formerly very extensively used in large dynamos, owing to the low centre of gravity of its revolving armature

resulting in increased stability and freedom from vibration, as compared with the overtype pattern. In most cases the whole of the field magnet is composed of wrought-iron, the two limbs being formed of rectangular slabs bolted to the yoke. As a rule, this class of field magnet is supported upon a bedplate of cast-iron, and therefore it is necessary to magnetically separate its pole pieces therefrom, otherwise they will be magnetically short circuited, or the lines of force will flow through the bedplate in place of passing through the armature core. To

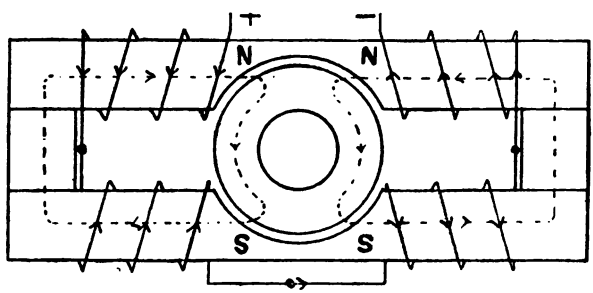


FIG 64.

effect this the pole pieces are supported at a suitable distance from the bedplate by "footsteps," S S, or brackets of zinc, brass, or other non-magnetic substance.

Consequent Pole Field Magnets. — The two leading types of consequent pole field magnets are illustrated in Figs. 63 and 64. The paths and directions of the lines of force in the field and armature cores are indicated, as before, by the dotted arrowheads and lines. Fig. 63, which represents the "Manchester" type of field magnet, may be looked

upon as a double magnet, the exciting coils being wound upon what may be regarded as the yokes of the magnets. The directions of the electric current flowing in the magnetising coils are such that two similar poles are produced in each pole piece. In Fig. 64 two similar poles are produced in each pole

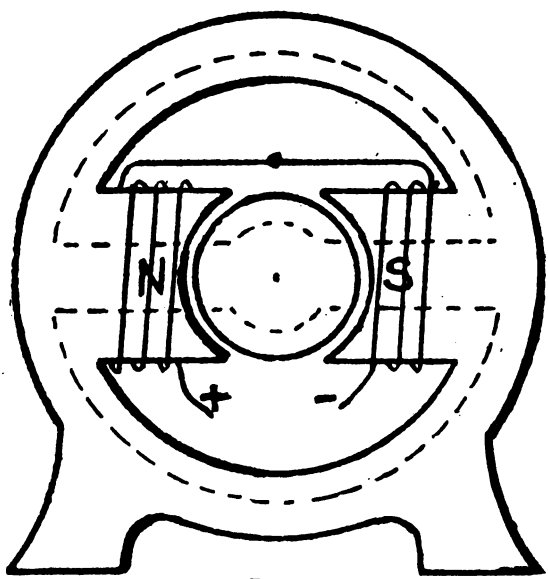


FIG. 65.

piece as in the "Manchester" type, but four exciting coils are necessary, these being wound upon the limbs of the magnet, and connected up in a suitable manner to produce the requisite polarity in the pole pieces.

Iron-Clad Field Magnets.—The generally accepted form of this field magnet is shown in Fig. 65. It consists of an external ring of iron forming the

yoke and provided with inwardly projecting poles, upon which the exciting coils are wound or slipped, terminating in pole pieces. This method of construction has the advantages of strength, simplicity, symmetrical appearance, and minimum magnetic leakage, since the pole pieces are almost entirely

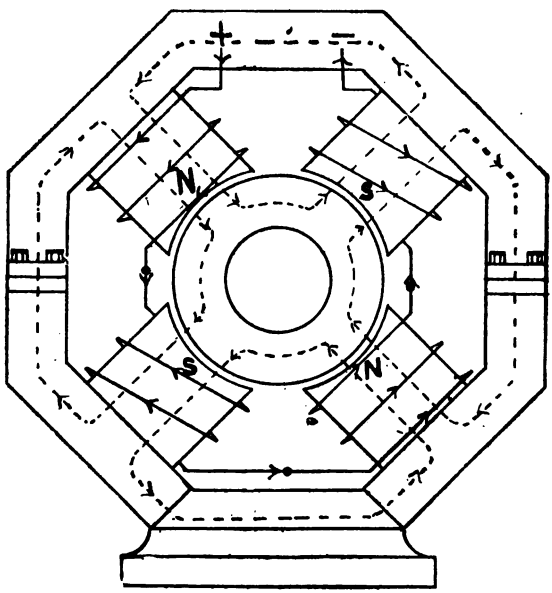


FIG. 66.

enclosed or surrounded by the iron-clad external casing forming the yoke of the magnet. This last property causes this type of field magnet to be universally adopted in ship installations owing to its non-liability to affect the compass by stray magnetism.

Multipolar Field Magnets.—Up till within a comparatively recent period the bi-polar type of field magnet was almost invariably used for all sizes of machines, even up to 100 kilowatts. Its use has now, however, been discontinued except in sizes below 6 kilowatts, owing to the greater efficiency of the multipolar type. These generally consist of 4, 6, 8, or more magnet poles arranged in alternate order around the armature. They may be arranged into two classes, according as the poles are salient or con-

FIG. 67.

sequent. The salient pole form is most commonly adopted, Fig. 66 showing a pattern sometimes used. It consists of a ring of iron, having four pole pieces projecting inwardly, over which the exciting coils are slipped, the ring forming a common yoke for all the poles. As a rule, it is made in two portions, bolted together horizontally, so that the upper portion may be lifted off for examination of the armature. Owing to its cheaper and more symmetrical form the cylin-

drical pattern is, however, now almost universally adopted, Fig. 67 showing its standard form. Fig. 68 is given as an example of the consequent pole type of multipolar field magnet. The magnet cores are of wrought-iron, bolted on to wrought-iron pole pieces, the magnetising coils being coupled up so as to pro-

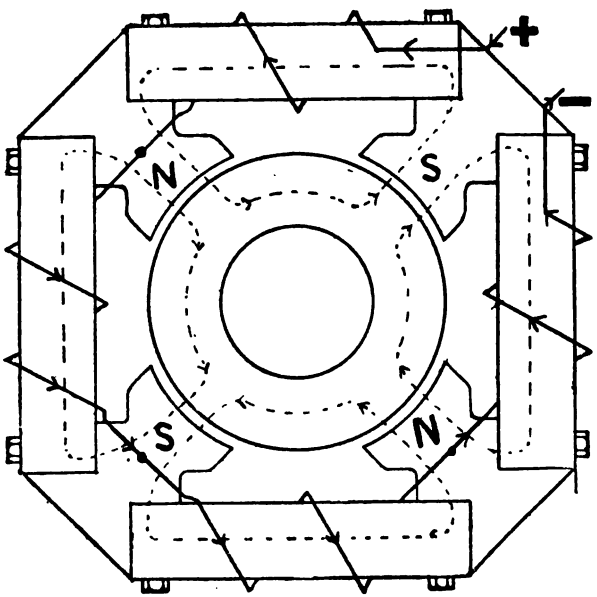


FIG. 68.

duce consequent poles of alternate polarity around the armature. Fig. 69 shows an 8-pole multipolar field magnet fitted with the smaller compensating or commutating poles already referred to, arranged between the main magnet poles.

Field Magnet Windings.—The insulated wires

used for the excitation of the field magnets, not being subjected to any of the detrimental influences experienced by the armature conductors, are in most cases of solid copper. In some cases the wires are wound upon insulated spools, which are afterwards slipped over the limbs of the magnet; in others,

FIG. 70.

they are wound direct upon the core of the field magnet, this latter being previously insulated with vulcanised fibre or other insulating material. The most commonly adopted practice, however, is to wind the insulated wire upon suitably shaped wooden formers. When the whole of the insulated wire has been wound upon the former, this is withdrawn,

leaving a hollow coil; this is then served with tape, dipped in an insulating compound and thoroughly baked. Fig. 70 shows a field coil of this description, as used by the Lancashire Dynamo and Motor Co. on their machines. These particular coils are each provided with two terminals so that no loose wires project, thus avoiding the danger of the latter being broken off. The coils are held in their place on the poles by a brass plate, top and bottom, enabling the air to circulate freely both inside and outside the coil, and ensuring cool running of the coil. In general, the wires used for the exciting coils of shunt wound dynamos are very thin; hence when this is used for making connection to the terminals of the machine, it is very liable to break off near the flanges of the reel upon which it is wound. Several plans are adopted to prevent this occurring: in some cases the ends of the shunt coils are soldered to stouter wires within the flanges of the bobbins, these wires being afterwards connected to the terminals of the machine; in other cases, the ends of the coils are soldered to large terminals fixed upon the flanges of the bobbins, these terminals being afterwards suitably connected together by strips of copper.

Coupling up Field Magnet Coils.—In coupling up the exciting coils of dynamo field magnets, the primary essential is to so arrange the connections of the coils that the magnetising current flowing through them produces the requisite polarity in the respective pole pieces. In those field magnets provided with a single coil only (as in Fig. 60), not much difficulty will be experienced in coupling up; when two or more coils are used, however, it is possible to so

arrange the connections that poles are produced in the yokes or other portions of salient pole field magnets; or in the case of consequent pole field magnets, the connections may even be so arranged that the coils neutralise each other, and no external field whatever is produced. The manner in which the coils of the various types of salient and consequent pole field magnets are coupled up will be apparent from inspection of Figs. 60 to 68; but in order to still further facilitate the coupling up of field coils the following rule is given:—

Practical Rule for Coupling up Field Magnet Coils.—In coupling up the coils of either salient or consequent pole field magnet coils, assume each of the pole pieces to have a certain polarity (in bi-polar dynamos two poles only, a north and south pole respectively, are required; in multipolar dynamos the poles must be arranged in alternate order around the armature, the number of N and S poles being equal), then apply the rule given on page 21 to each of the coils, and ascertain the direction in which the magnetising current must flow in each in order to produce the assumed polarity in each of the pole pieces. Having marked these directions on the coils, the coils can be coupled up in either series or parallel according to requirements, so that the current flows in the necessary direction in each.

Connecting up Dynamos.—The manner in which the connections of the field magnet coils, and brushes, and terminals, are connected to one another, depends entirely upon the class of dynamo. The field magnet shunt coils of shunt and compound wound dynamos are invariably arranged in series with one another, and

[*To face page* 118.

SIX-POLE MULTIPOLAR DYNAMO.

then connected as a shunt to the brushes or terminals of the machine, as represented in Figs. 54, 56, and 57. The series coils of series and compound wound machines are arranged either in series or in parallel with one another, according to circumstances, and the amount of current given by the machine, and then connected in series to the armature and external circuits upon the principle shown in Figs. 52, 56, and 57.

CHAPTER VIII.

REGULATING DYNAMOS.

IN the practical operation of dynamos, some means of regulating their output are always needed, so that either the voltage or the current may be maintained at a constant value, or varied as required. The output of a dynamo may be regulated or varied by any of the following methods, or by a combination of the same:—(1) *Variation of speed of armature.* (2) *Variation of strength of magnetic field.* (3) *Variation of position of brushes on commutator.* (4) *Variation of resistance in dynamo circuit.* The application of these methods of regulation to the various classes of dynamos is considered in the succeeding paragraphs.

Regulating Separately Excited Dynamos.—As previously mentioned (p. 90), the voltage and output of this class of machine is most commonly governed by varying the strength of the magnetising current flowing through its field magnet coils. When the magnetising current is furnished by a battery or accumulator, this is effected either by means of a hand regulator or rheostat inserted in the exciting circuit (as represented in Fig. 51), or by varying the number of cells in circuit, this latter being the most

economical plan. In most cases, however, a smaller dynamo is used for the purpose. In this case the strength of the magnetising current flowing in the coils of the main dynamo may be regulated by either of two methods:—(*a*) by means of a hand regulator inserted in the field circuit as before; or (*b*) by varying the voltage of the smaller exciting dynamo. This latter may be effected either by varying the speed of the armature, or by varying the strength of the magnetic field, by regulating the strength of the magnetising current flowing in the field coils by means of a hand regulator. When several separately excited dynamos are running together, it is a common practice to employ a smaller exciting dynamo for the exclusive purpose of supplying the magnetising current required for the field magnets of the several dynamos. The system of regulation then adopted depends upon whether the dynamos are supplying a common circuit, or running in parallel, or supplying independent circuits. The conditions of working in the former case require that the voltage of all the machines shall be varied simultaneously, and therefore the method of regulation, by varying the voltage of the smaller exciting dynamo, may be used with advantage. In the latter case, however, since each machine supplies an independent circuit, the voltages of which may vary greatly, such a method is obviously not applicable, for any variation of current will affect all the dynamos in common. It is therefore usual in such cases to provide the field circuit of each individual dynamo with a field regulator, so that its pressure may be adjusted independently of the others.

Field Regulators.—These, when applied to the regulation of dynamos, consist of multiple contact switches, so arranged that (A)—either the resistance of the field magnet circuit can be varied by inserting or removing resistance either in series or in shunt or parallel with the field windings, or (B)—one or more of the field coils may be cut into or out of the circuit or short-circuited. When arranged for performing the former operation (A), the regulator is usually combined with a set of resistance coils, a combination of this description, constituting a "field regulator," being illustrated in Fig. 72. This field regulator is of the well-known "Ward-Leonard" pattern, consisting of a circular cast-iron plate, upon one side of which is carried the contacts and resistance material, this being composed of high resistance wire or strip in a crinkled form. The resistance material is embedded in and covered by a porcelain enamel which retains it firmly in place and protects it from the oxidising action of the air. The contacts are so disposed that a lever can be moved over all of them by the rotation of a central spindle. The number of contacts provided varies in accordance with the size of the dynamo field to be controlled.

FIG 72.

The field regulator is usually fixed at the back of the switchboard, being controlled from the front by a central spindle projecting through the front of the switchboard, and actuated by a hand wheel, as shown in Fig. 72. When the regulator is arranged for performing the latter operation (B), the switch is not combined with a resistance, but the exciting coils of the field magnets are divided up into groups and the ends are connected to the contacts or terminals in place of the resistance coils, so that by varying the position of the lever each of the exciting coils may be cut into or out of circuit, and the strength of the magnetic field adjusted accordingly.

Regulating Series Dynamos.—The series dynamo is ordinarily used for operating series arc lamp circuits, and for the electric transmission of power, its regulation being effected by any of the following methods:—

(1) *Variation of strength of magnetic field.*

(2) *Variation of speed of armature.*

(3) *Variation of position of brushes on commutator.*

(1.) **Regulation by Variation of Strength of Magnetic Field.**—Although theoretically there are several different methods of varying the strength of the magnetic field of a series dynamo, in practice the method of shunting the exciting current in the field coils is invariably followed. The essential principle of this method consists in establishing a shunt of variable resistance across the field coils, so that a

portion of the armature current is shunted through the resistance, the remainder being used for exciting the field magnets. The strength of the magnetic field being proportional (within certain limits) to the strength of the magnetising current flowing in the exciting coils, it follows that the E. M. F. of the machine will vary in proportion to the resistance of the shunt. By reducing the resistance of the latter, a larger proportion of the total current will flow through it, and the strength of the current flowing in the field coils being thus reduced, the voltage of the machine will be reduced also, or *vice versa*. The alteration in the resistance of the shunt can be effected by hand, with the aid of a rheostat or hand regulator, similar in principle to that represented in Fig. 72. When used for this purpose, however, the hand regulator is usually so arranged that all the resistance coils can be cut out of circuit, and the field coils short-circuited, thus allowing of the voltage of the machine being adjusted from zero to the maximum value.

Automatic Regulation.—In cases where an approximately constant current is to be maintained in a circuit, as in series arc circuits, the adjustment of the resistance of the variable shunt is, as a rule, effected automatically by means of some electromagnetic device, actuated by solonoids placed in the main circuit.

Brush's Automatic Regulator.—The automatic regulator invented and used by Brush for the purpose of maintaining a constant current in an arc circuit is shown diagrammatically in Fig. 73. The current leaving the positive brush of the dynamo (D) divides at the junction of the field magnet coils (F M) and

the shunt (S) part, passing through the former, and part through the latter. Included in the shunt circuit (S) is a variable resistance (C) composed of a pile of carbon slabs or blocks, arranged one upon another in a press in such a manner that the current passing in the shunt must pass from one block to another. These slabs, when pressed together, conduct well; but

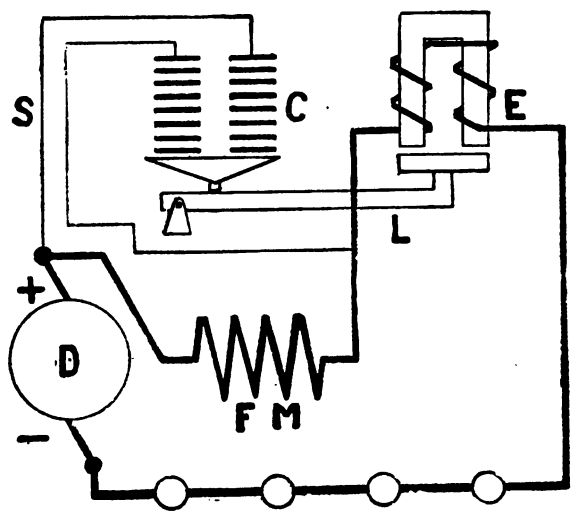


FIG. 73.

when the pressure is diminished, their imperfect contact greatly increases the resistance of the shunt. Hence, when the lever and armature (L) is raised or lowered by the action of the current flowing in the solonoid or electro-magnet (E), which is included in the main circuit, the pressure on the slabs is increased or diminished, and the resistance of the shunt varied in proportion. If now some of the lamps be cut out

of circuit by short-circuiting them, the resistance of the circuit will be diminished, and there will be a tendency for the current to increase above its normal value. This increase of current will cause the solonoid (S) to attract the lever (L) with greater force, resulting in an increase of pressure on the carbon slabs, and a diminution of the resistance of the shunt. As a consequence, a larger proportion of the total current flowing will be shunted across the field coils, and the magnetic field being thus weakened, the E. M. F. of the machine will be correspondingly reduced, and the current thus maintained at its normal value.

Regulation by Variation of Speed of Armature.—The voltage and output of series dynamos can be governed to some extent by varying the speed of the armature, by opening or closing the stop-valve of the steam engine, or other motor driving the dynamo. This method of regulation is, however, only applicable in cases where the fluctuations of the load are small, since it involves constant attendance on the engine.

Electric Governor.—To obviate this constant attention to the engine when this system of regulation is adopted, an electric governor is frequently employed. One of the best known types of electric governor is that of Richardson, manufactured by Messrs Robey & Co., Lincoln. This governor may be used for maintaining either a constant pressure, or a constant current in a circuit, and is shown fitted to a steam engine in Fig. 74. The governor consists of a solenoid (E), the cores of which are attached to the end of a lever (L), the short end of which presses through the medium of a plunger (P), direct upon the

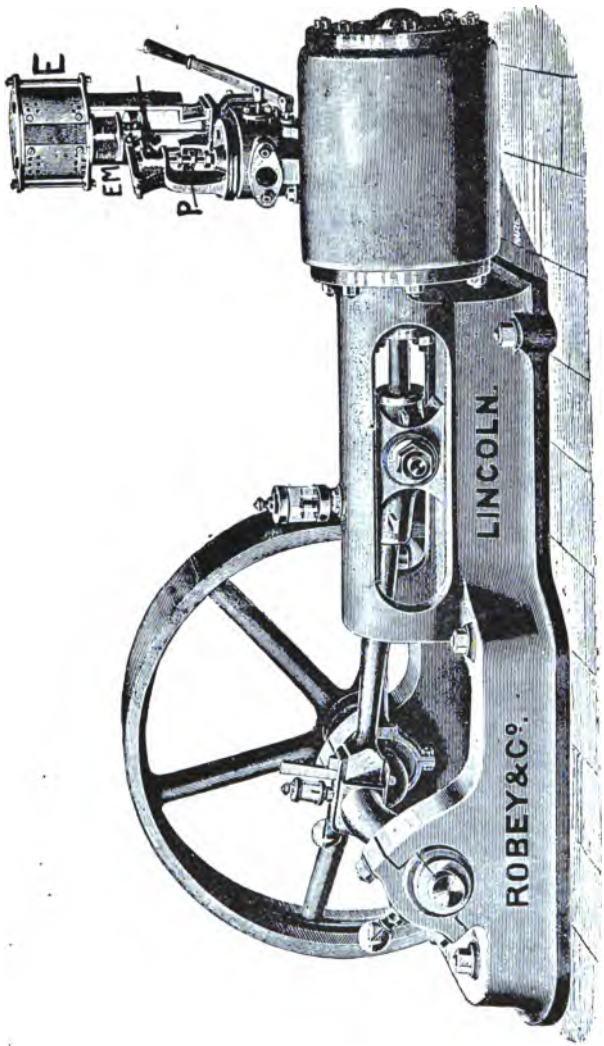


FIG. 74.

stalk of a double-beat cornish valve. The valve fits freely into its seat, and works almost without friction. It is, however, so arranged that the steam gives it a constant pressure upwards. This is balanced at the other end by a spring, and as the leverage is six to one, the spring only needs to exert a sixth of the pressure. There are therefore two forces acting in contrary directions, and nearly balancing each other, and when an electric current is sent through the coils of the solenoid (E), which, when intended for maintaining a constant current, are included in the main circuit, the cores are drawn further in, and the valves partially closed. The parts are so balanced and adjusted that the slightest change in the strength of the current is at once felt and responded to by the engine, and the speed of the armature adjusted to suit the work being done. As an additional precaution, a separate small electro-magnet (E M) is included in the circuit of the solonoid, which, when the current is flowing therein, holds up the iron block (B). If from any cause the circuit is broken, the block (B) falls, and instantly cuts off the steam, thus stopping the engine.

Regulation by Variation of Position of Brushes on Commutator.—In both ring and drum armatures, when rotating in a bi-polar field, there are two points situated at opposite extremities of a diameter of the commutator, at one of which the potential is a maximum, and at the other a minimum, and it is at these points that the brushes must be placed, in order to obtain the greatest difference of pressure. From the point of maximum potential to the point of minimum potential either way round the commutator, the

pressure gradually decreases in value. Hence, if the brushes make contact at points on the commutator other than the neutral points or points of highest and lowest potential, the pressure between the brushes will vary in proportion to their distance from the neutral points, increasing as they approach the neutral points, and decreasing as they recede from them, until when making contact at points situated at about 90° from the neutral points, they will be at nearly the same potential. From this it follows that by merely rocking the brushes round the commutator, the pressure at the terminals of the machine may be varied and regulated as required. Such a method of regulation cannot, however, be used with advantage in ordinary dynamos, owing to the very destructive sparking which takes place at the brushes when they are moved any considerable distance from the neutral points. Special dynamos have been designed, notably by Statter, to meet the special requirements of this method of regulation, and in which the sparking at the brushes is obviated at all loads within the range of the machine, but as these have not come into general use they need not be further considered here.

Regulation of Shunt Dynamos.—In parallel incandescent lighting, it is absolutely necessary to maintain the pressure at the lamps at a constant value. When the lamps are situated at a considerable distance from the machine, as in town lighting, this necessitates a constantly varying pressure at the machine in order to make up for the fall of pressure in the mains connecting the machine to the lamps, which fall is dependent on the amount of current flowing

in the mains. The ease with which this variation of pressure can be effected in the shunt dynamo causes this class of machine to be ordinarily used in central stations for incandescent lighting, the regulation being effected by either of the following methods, or by both in conjunction. (1) *Variation of strength of magnetising current.* (2) *Variation of speed of armature.*

(1.) **Regulation by Variation of Strength of Magnetising Current.**—This is the only thoroughly efficient method of regulation for a shunt dynamo.

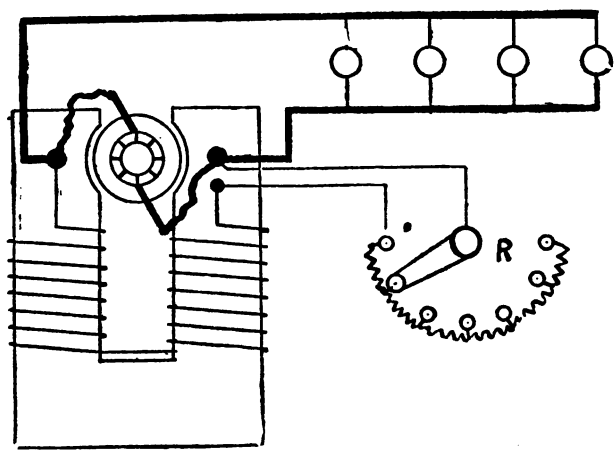


FIG. 75.

The variation in the strength of the magnetising current is effected by means of a hand regulator or rheostat, similar to that represented in Fig. 72, which is inserted in the shunt circuit of the machine, as shown diagrammatically in Fig. 75. In this system of regulation, the resistances of the field magnet shunt

windings and of the regulator coils are so proportioned, that, when no load is on the dynamo, and all the coils of the regulator are in circuit with the shunt, the machine generates the normal pressure required at the lamps. As more and more lamps are switched on, the voltage at the lamps has a tendency to decrease, and therefore the pressure at the machine must be raised in proportion. This is effected by moving the lever of the regulator (R), so that fewer resistance coils are included in the shunt circuit; the resistance of the latter being thus decreased, the exciting current and voltage of the machine is increased correspondingly. This method of regulation is common with all in which resistances are included in the circuit, wastes energy to a certain extent, but the quantity so wasted is so small in proportion to the whole that it may be considered as of little moment, especially when the advantages of the system are taken into account. It is possible, of course, to use this method in conjunction with regulation by means of the engine stop-valve (the stop-valve being used for large variations of pressure, and the hand regulator for small variations), but the advantages of the system are so few that in the generality of cases the hand regulator is solely relied on to cope with any variations in the load. The engines are then so arranged that they can be run entirely upon their governors, these being so adjusted as to merely prevent the engine racing in case of the load being suddenly taken off the machine, through a short circuit, or other breakdown, the stop-valves being fully opened as soon as the machines have taken the load.

Regulation by Variation of Speed of Armature.—A much less satisfactory method of regulation for shunt dynamos is that of varying the speed of the armature. For small variations of pressure, the alteration of speed can be readily effected by means of an adjustable governor, the speed of the armature being varied by increasing or diminishing the tension of the governor spring, according to the pressure required at the terminals of the machine. For larger variations, however, the only effective method of regulation is by means of the stop-valve, that is to say, the main stop-valves of the engines are opened or closed in proportion to the pressure required. When a number of dynamos are running in parallel, the disadvantages of this system, as compared with the method of varying the strength of the magnetic field, become especially prominent, since, in place of a number of easily adjusted hand regulators, fixed in some central position, and operated by a single attendant, this method involves the regulation being effected by probably as many men as there are engines, each regulating the stop-valve of a particular engine. Furthermore, the regulation is not nearly so effective, owing to the difficulty of expeditiously adjusting the valves to give the pressure required. Owing to these drawbacks, this system of regulation is not now generally employed, except in the case of small installations and sometimes on ship-board, where a prejudice exists against governors in general, many engineers preferring to regulate direct by means of the stop valve.

Regulating Compound Dynamos.—A carefully compounded dynamo will, when run at the speed for

which it was designed, regulate itself perfectly, and maintain a constant difference of potential at its terminals under any variation of load within its range. In practice, however, it is not always possible to work a dynamo under these exact conditions, and, moreover, in the case of large machines, the effect of temperature upon the resistance of the machine has an appreciable effect upon the voltage. Means for regulating the latter are therefore desirable. The voltage may be varied to a certain extent by suitably adjusting the governor of the driving engine, increasing or decreasing the speed; but in many cases this is not very desirable or possible, and a much better method of obtaining the desired variation of voltage is to insert a variable resistance or hand regulator in the shunt circuit of the machine, the resistance of the shunt being suitably proportioned to give the requisite margin for regulation.

Regulating Over-Compounded Dynamos.—It is sometimes desirable, as in central light and power stations, to have a dynamo which will maintain a constant pressure at a point some distance from the machine. In this case the dynamo is over-compounded, or the series coils are wound with a greater number of turns, in order to raise the pressure at the terminals of the machine as the load increases, and thus compensate for the fall of pressure in the mains. As it is frequently necessary to vary the degree of over-compounding, the series coils of such dynamos are usually so proportioned as to give from 10 per cent. to 20 per cent. of over-compounding, and the machine is provided with a "diverter." This consists of a strip or ribbon of German silver or copper, which

is arranged as a shunt to the series coils. By suitably including a greater or lesser length of ribbon in the circuit, the resistance of the variable shunt and the amount of current flowing in the series coils can be varied, and the percentage of over-compounding adjusted accordingly.

CHAPTER IX.

COUPLING DYNAMOS.

WHEN it is needful to generate a large and variable amount of electrical energy, as is the case in large installations and central generating stations, apart from the question of liability to breakdown, it is neither economical nor desirable that the whole of the energy should be furnished from a single dynamo. Since the efficiency of a dynamo is dependent upon its output at any moment, or the load at which it is worked, the efficiency varying from 95 per cent. at full load to 80 per cent. at half load, it is obviously advisable in order to secure the greatest economy in working to operate any dynamo as far as possible at full load. Taking the efficiency of the prime mover driving the dynamo into consideration under like conditions, if this be a steam engine the combined efficiency of the plant will be still further reduced, since a steam engine requires from 30 to 50 per cent. more steam per horse-power at one-half load than it does at full load; while it is only about one-third as efficient at one-quarter load as at full load. Under the above circumstances, when the whole of the output is generated by a single dynamo the greatest economy in working can evidently not be effected, for the load will naturally fluctuate up and down during

the working hours, as the lamps, motors, &c., are switched into and out of circuit; and hence, although the dynamo may be working at full load during a certain portion of the day, at other times it may probably be working below half load, and therefore the efficiency and economy in working in such an arrangement is very low. In order to secure a maximum efficiency, it is usual in such cases to divide up the generating plant into a number of units, varying in size, so that as the load fluctuates it can either be shifted from one dynamo to another as the exigencies of the case requires; or when the load exceeds the capacity of the largest dynamo in the plant, the output of one can be added to that of another, and thus the dynamos actually at work at any moment can be operated as nearly as possible at full load. As it is necessary to take certain precautions in connecting one dynamo to another, in order that the other dynamos may not be affected by the change, and that they may work satisfactorily together, it is well to consider these in connection with the different types of machines.

Series and Parallel Connections.—Since the output of a dynamo is made up of two factors, viz., the pressure and the current respectively, it follows that the output of a machine may be increased by increasing either the one or the other, or both at the same time. As however the systems of distribution in use at the present time involve the maintenance of either *a constant current* or a *constant pressure* in a circuit, the methods of coupling dynamos together resolve themselves into two kinds, corresponding to the systems of distribution, viz., *parallel* and *series* con-

nections. In coupling two or more machines in parallel, the pressures of all the machines are kept at a constant value, while the output of the plant is increased in proportion to the current capacities of the machines in circuit. In the series coupling, the current capacity of the plant is kept at a constant value, while the output is increased in proportion to the pressures of the machines in circuit.

Shunt Dynamos in Series.—The simplest operation in connection with the coupling of dynamos, and the one used probably more frequently in practice than any other, is the coupling of two or more shunt dynamos to run either in series or in parallel. When connected in series, the positive terminal of one machine is joined to the negative of the other, and the two outer terminals are connected through the ammeter A, fuses F_1 F_2, and switch S, to the two main conductors or omnibus bars as represented in Fig. 76. The machine will operate when the connections are arranged in this manner, if the ends of the shunt coils are connected to the terminals of the respective machines; but a better plan is to put both the coils in series with one another, so that they form one long shunt between the two main conductors, as shown in Fig. 76. When arranged in this way, the regulation of both machines may be effected simultaneously by inserting a field regulator (R) in series with the shunt circuit, as represented.

Shunt Dynamos in Parallel.—The coupling of two or more shunt dynamos to run in parallel is effected without any difficulty, and is probably an operation more frequently performed than any other, it being daily practised in central generating stations

on the low tension system. Fig. 77 illustrates diagrammatically the method of arranging the connections. The positive and negative terminals of each

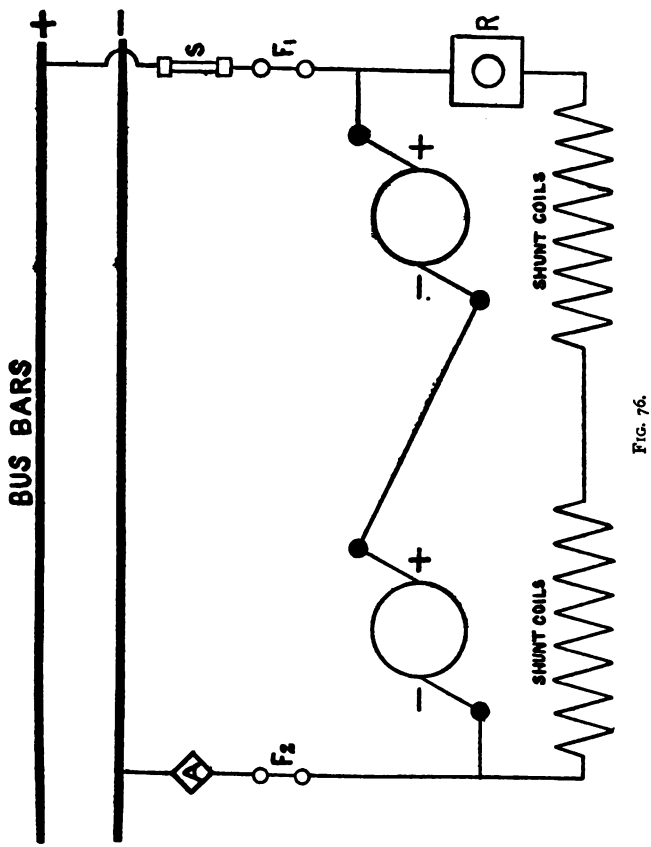


FIG. 76.

machine are connected respectively to two massive insulated copper bars, shown at the top of the diagram, and called omnibus bars, through the double

pole switches S_1 S_2, and the double pole fuses F_1 F_2. Ammeters, A_1 A_2, are inserted in the main circuit of each machine, and serve to indicate the amount of

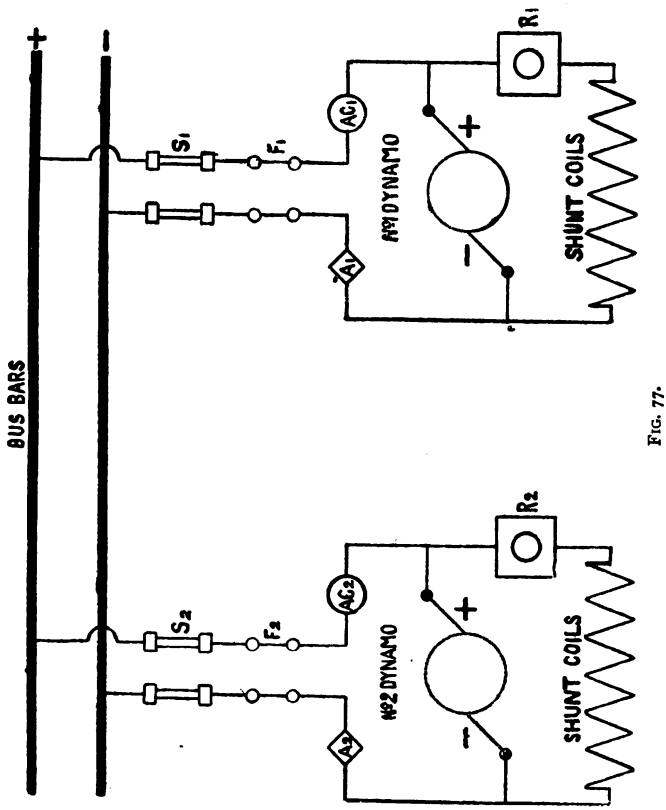


FIG. 77.

current generated by each. An automatic switch or cutout, AC_1 AC_2, is also shown as being included in the main circuit of each of the machines, although this

appliance is sometimes dispensed with. The pressure of each of the machines is regulated independently by means of the field regulators R_1 R_2, inserted in series with the shunt circuit. The shunt circuits are represented as being connected to the positive and negative terminals of the respective machines, but in many cases, where the load is subjected to sudden variations, and when a large number of machines are connected to the bus bars, the shunt coils are frequently connected direct to these; and in such circumstances this method is preferable, as by means of it the fields of the idle dynamos can be excited almost at once direct from the bus bars by the current from the working dynamos, and hence if a heavy load should come on suddenly, no time need be lost in building up a new machine previous to switching it into parallel. The pressure of the lamp circuit is given by a voltmeter, whose terminals are placed across the omnibus bars; and the pressure at the terminals of each of the machines is indicated by separate voltmeters or pilot lamps, the terminals of which are connected to those of the respective machines.

Switching Dynamo into and out of Parallel.—In order to put an additional dynamo into parallel with those already working, it is necessary to run the new dynamo up to full speed, and, when it excites, regulate the pressure by means of the field regulator until the voltmeter connected to the terminals of the machines registers one or two volts more than the voltmeter connected to the lamp circuit, and then close the switch. The load upon the machine can then be adjusted to correspond with that upon the

other machines by means of the field regulator. In this class of machine there is little or no danger of overloading an armature when connecting it to the bus bars, and therefore the pressure need not be adjusted with very great accuracy; in fact, it is common practice in central stations to judge of the voltage of the new dynamo merely by the appearance of its pilot lamp. When shutting down a machine, the load or current must first be reduced, by gradually closing the stop-valve of the engine, or inserting resistance into the shunt circuit by means of the field regulator; then when the ammeter indicates nine or ten amperes, the main switch is opened, and the engine stopped. By following this plan, the heavy sparking at the switch contacts is avoided, and the tendency for the engine to race reduced. Great care, however, has to be taken that the current is not reduced too far, or otherwise there is a risk of the machine being stopped, receiving a back current from the other dynamos, resulting in heavy sparking at the commutator, and in the machine being driven as a motor. To obviate this danger, and to render these precautions needless, shunt dynamos when running in parallel are frequently provided with reverse current circuit-breakers, set so as to automatically switch out the machine when the current falls below a certain minimum value.

Dividing Load.—If a plant composed of shunt dynamos running in parallel be subjected to variations of load, gradual or instantaneous, the dynamos will, if they all have similar characteristics, each take up an equal share of the load; if, however, as is sometimes the case, the characteristics of the dynamos are dissimilar, the load will not be shared equally; the

dynamos with the most drooping characteristics taking less than their share with an increase of load, and more than their share with a decrease of load. If the difference is slight, it may readily be compensated by means of the field regulator increasing or decreasing the pressures of the machines, as the load varies or fluctuates. If, however, the difference is considerable, and the fluctuations of load very rapid, it becomes practically impossible to evenly divide the load by this means so that each dynamo takes up its proper share of the work. Under such circumstances, the pressure at the bus bars is liable to great variations, and there is also great liability for the fuses of the overloaded dynamos to be blown, thus precipitating a general breakdown. To cause an equal division of the load amongst all the dynamos, under such circumstances, it is needful to insert a small resistance in the armature circuits of such dynamos as possess the straightest characteristics, or of such dynamos as take more than their share of an increase of load. By suitably adjusting or proportioning the resistances, the pressures at the terminals of all the machines may be made to vary equally under all variations of load, and each of the machines will then take up its proper share of the load.

Circuit-Breakers.—Shunt and other dynamos are always liable when working to have the pressure at their terminals reduced, either through a fault in the armature or field circuits, or through a hot bearing or other cause. When a number of shunt dynamos are running in parallel, and the pressure of one falls below that of the others, the load is transferred from the machine having the lower pressure to the machine

with the higher pressure, until when the pressure falls below a certain minimum value a reverse current is sent through the armature of the machine whose pressure has been reduced by the machines having the higher pressure. This results in the machine being driven as a motor, and frequently in great sparking at the commutators of all the dynamos, and also in an overload of the driving dynamos, and probably in the blowing out of all the fuses. In order to prevent this occurring, shunt dynamos when running in parallel are each as a rule provided with a reverse current circuit-breaker, placed between one or both of the machine terminals and the omnibus bars, whose duty it is to switch off automatically the machine in the event of a reduction of its voltage from any of the above-mentioned causes. The principle and action of this instrument will be understood by reference to Fig. 78, which represents the form manufactured and used for this purpose by Messrs Switchgear Co. Limited, Birmingham. The instrument illustrated consists of a useful combination of overload circuit-breaker with reverse current relay. When applied to the purpose of protecting a generator, its duties as a maximum or overload circuit-breaker are to prevent the armature or other windings of the generator being burnt up in the event of a short circuit or overload taking place in the external circuit. The purpose of the reverse current relay is to cut out the generator should the latter break down from any cause; it also prevents a switchboard attendant attempting to switch in a standing generator. Briefly described, the instrument consists of a main brush of hard laminated copper and of a size pro-

portionate to the current to be carried. This brush is forced into contact with the contact-plates connected to the line by means of the handle shown in

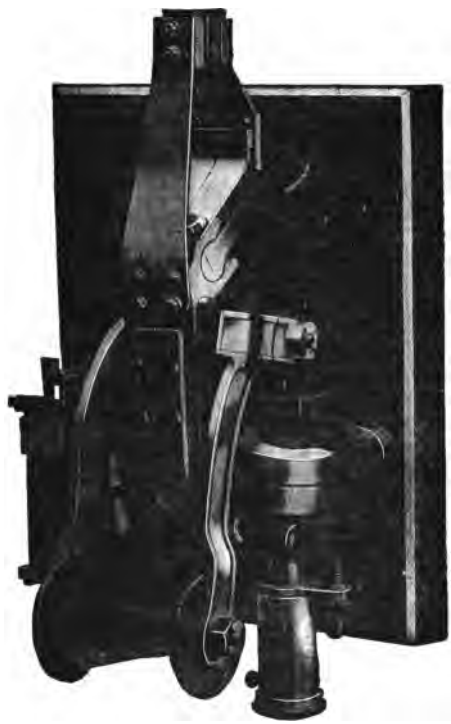


Fig. 78.

the illustration, being held in place by a catch or trigger. A magnetic coil or solenoid, shown to the right of the illustration, is connected in series with the

main brush, and when the current exceeds a predetermined limit, usually twice the full load current, the solenoid attracts a metal plunger which trips the catch or trigger, and the main brush breaks circuit. The action of the reverse current relay is, in effect, to trip the catch when a reverse current passes, usually amounting to 5 to 10 per cent. of the full load current. Auxiliary copper tips are provided to break after the main brush and prevent this being fused by the arc at breaking contact; the carbon tips shown at the top of the illustration finally breaking the circuit without damage to the contacts. A special tripping knob is provided by means of which the circuit-breaker may be opened with its full rapidity by hand. A "time lag" is shown as being fitted to the instrument, the object of this attachment being to allow an overload, which may be of a temporary nature only, to exist for a pre-determined length of time before the circuit-breaker cuts out the generator.

Coupling Series Dynamos in Series. — Series wound dynamos will run satisfactorily together without special precautions when coupled in series, if the connections are arranged as in Fig. 79. The positive terminal of one dynamo is connected to the negative terminal of the other, and the two outer terminals are connected directly to the two main conductors or bus bars through the ammeter A, fuse F, and switch S. If it be desired to regulate the pressure and output of the machines, variable resistances, or field regulators R_1 R_2, may be arranged as shunts to the series coils, as represented, so as to divert a portion or the whole of the current therefrom.

Series Dynamos in Parallel.—Simple series wound

dynamos not being well adapted for the purpose of maintaining a constant pressure, are seldom in practice coupled in parallel; the conditions of working,

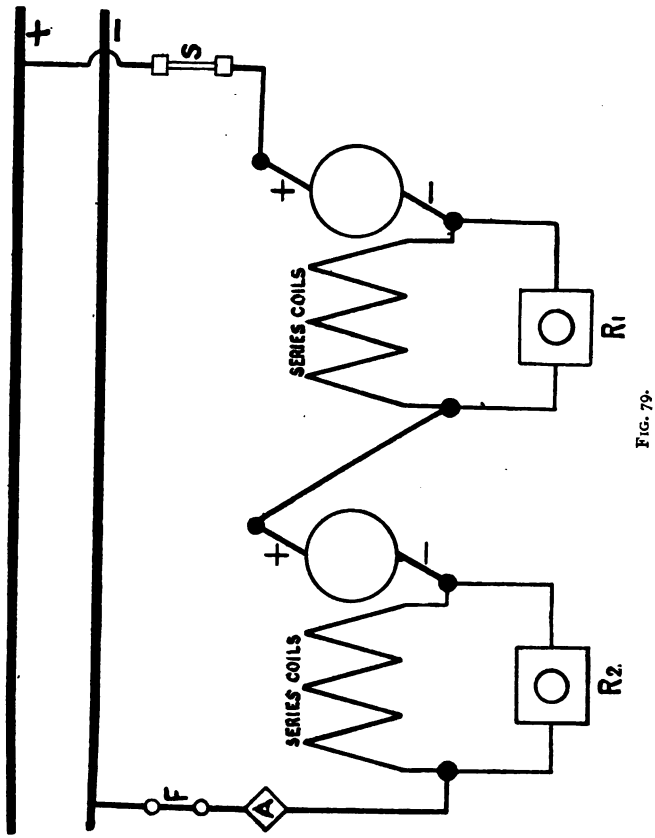


FIG. 79.

however, derive importance from the fact that compound dynamos, being provided with series coils, are subject to similar conditions when working in parallel,

which is frequently the case. In coupling two or more plain series dynamos in parallel, the same procedure cannot be followed as in the case of plain shunt dynamos, for the reason that if the voltage of the new dynamo is exactly equal to that of the bus bars when connected in parallel, the combination will be unstable. If from any cause the pressure at the terminals of one of the dynamos falls below that of the others, it immediately takes a smaller proportion of the load; as a consequence, the current in its field coils is at once reduced, and a further fall of pressure immediately takes place owing to this circumstance. This increased fall of pressure again causes the dynamo to relinquish a portion of its load, and again occurs a further fall of pressure. Thus the process goes on, until finally the dynamo ceases to supply current, and the current from the other dynamos flowing in its field coils in the reverse direction reverses its magnetism, and causes it to run as a motor against the driving power in the opposite direction to that in which it previously ran as a dynamo. Under such circumstances the armature is liable to be destroyed if the fuse is not immediately blown, and in any case is subjected to a very detrimental shock. This tendency to reversal in series dynamos can be effectually prevented by the simple expedient of connecting the field coils of all the dynamos in parallel, as was first suggested by Gramme. This is effected in practice by connecting the ends of all the series coils where they join on to the armature circuit by a third connection, called the "equalising connection," or "equaliser," as shown in Fig. 80. The immediate effect of this equalising connection is to cause the

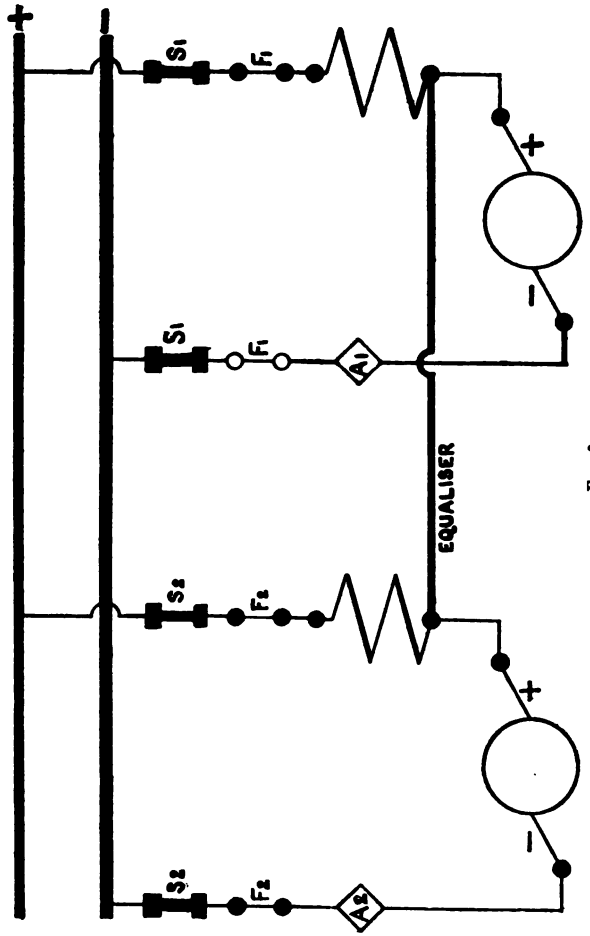


FIG. 80.

whole of the current generated by the plant to be divided among the series coils of the several dynamos in the inverse ratio of their resistance, without any regard as to whether this current comes from one armature, or is divided among the whole. The fields of the several dynamos being thus maintained constant, or at any rate caused to vary equally, the tendency for the pressure of one dynamo to fall below that of the others is much diminished, reversal of polarity is entirely obviated, and the machines will run together under all conditions of load.

Coupling Compound Dynamos in Series.—Since compound dynamos may be regarded as a combination of the shunt and series wound machines, and as no special difficulties are experienced in running these latter in series, analogy at once leads to the conclusion that compound dynamos under similar circumstances may be coupled together with equal facility. This is found to be the case in practice, it being only necessary, in order that two compound dynamos may run satisfactorily together in series, to connect the series coils of each together, as represented in Fig. 79; the shunt windings must be connected as a single shunt, as in Fig. 76, which may either extend simply across the outer brushes of the machines, so as to form a double short shunt, or may be a shunt to the bus bars or external circuit, so as to form a double long shunt.

Compound Dynamos in Parallel. — Compound dynamos will not run satisfactorily together in parallel, unless all their series coils are connected together by an equalising connection, as in series dynamos. Two methods of arranging the connections are adopted in practice, these being illustrated

in Figs. 81 and 82. The same reference letters are common in both diagrams—S_1 S_2 are switches; F_1 F_2 fuses; A_1 A_2 are ammeters, which indicate the total amount of current generated by each of the machines; AC_1 AC_2 are automatic switches, arranged for automatically switching out a machine

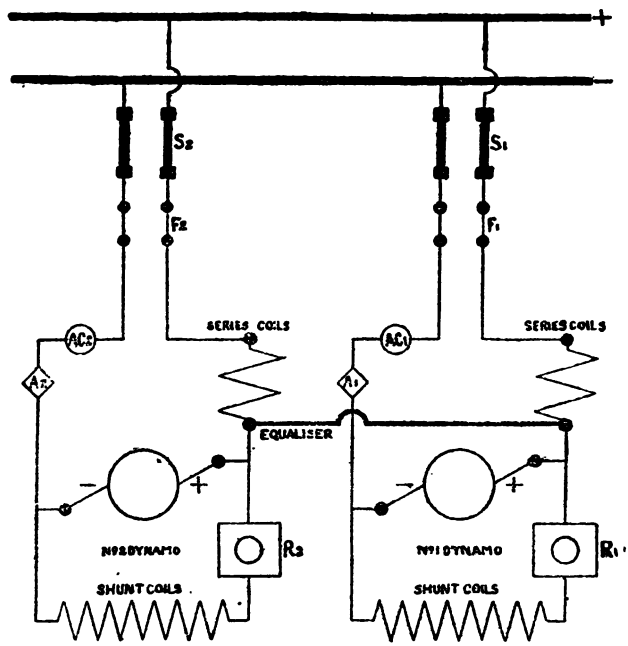


FIG. 81.

in the event of the pressure at its terminals being reduced through any cause; R_1 R_2 are hand regulators inserted in the shunt circuits of each of the machines, by means of which the pressures of the individual machines may be varied and the load upon each ad-

justed. The pressure at the bus bars is given by the voltmeter V, one terminal of which is connected to each of the bars; a second voltmeter may be used, to give the pressure of any individual machine, by connecting "voltmeter keys" to the terminals of each of the machines, or a separate voltmeter may be used for

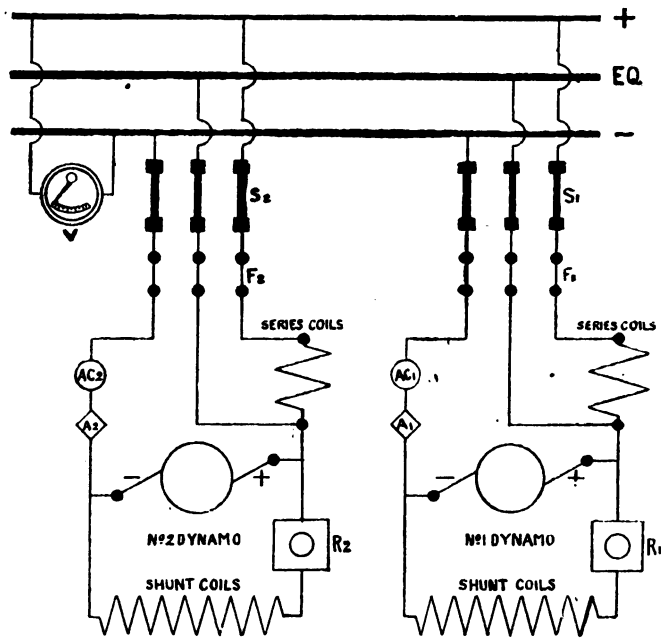


FIG. 82.

each individual machine. The only essential difference between the two diagrams is, that in Fig. 81 the equaliser is connected direct to the positive brushes of all the dynamos, whilst in Fig. 82 the equaliser is brought up to the switchboard and arranged between

the two bus bars. In connection with this latter arrangement the form of switch shown in Fig. 83 is generally used. This consists of three contacts, insulated from each other, and fixed upon a slate base; the two contacts at the sides are respectively connected to the positive and negative conductors, while the central contact is connected to the equaliser. The circuits are opened or closed simultaneously by means of three levers which are forced between the contacts by the handle. These levers are each provided with removable knife contacts for taking the spark at breaking contact, and are insulated from each other, and rigidly fixed upon a spindle which is capable of a small angular movement in the bearings, shown in the lower part of the figure.

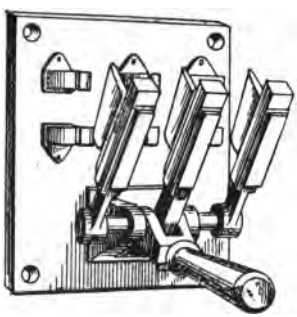


FIG. 83.

Compound Dynamos with Compensating Poles.—When compound dynamos fitted with compensating poles are to be run in parallel, it is needful to arrange the equalising connection so that only the armature current passes through the interpole windings under any circumstances, otherwise violent sparking is liable to occur when switching a machine into parallel. The correct connections, for two compound dynamos fitted with compensating poles, to enable them to run in parallel, are shown in the diagram, Fig. 84; from which it will be seen that the equalising connection is not made direct across

the brush-holders, as in the preceding diagrams, Figs. 81 and 82, but the connection is made at the junction of the interpole windings with the series.

Switching Dynamo into and out of Parallel.—If the characteristics of all the dynamos are similar, and the connections are arranged as in either Figs. 81

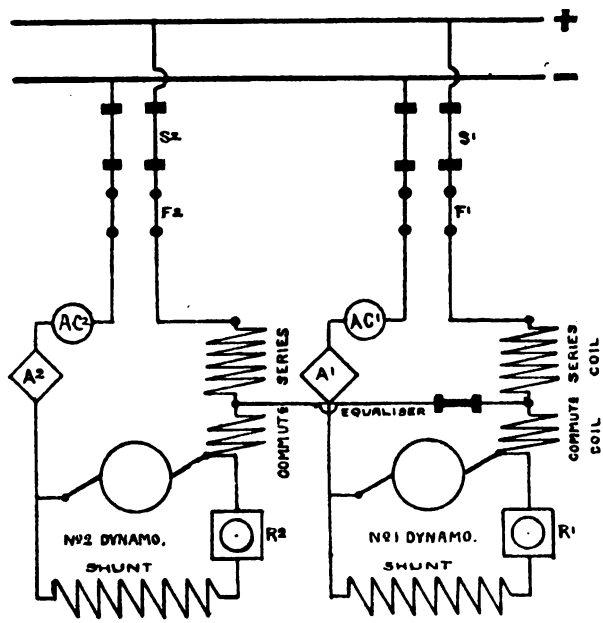


FIG. 84.

or 82, the only precaution to be observed in switching a new machine into parallel is to have its voltage equal, or nearly equal, to that of the bus bars previous to closing the switch. If this is the case, the new machine will instantly take up its due share of the load without disturbance or shock of any kind.

If a dynamo is to be cut out of circuit, it will first be necessary to reduce the load to a few amperes, as in the case of shunt dynamos, either by easing down the engine, or by cutting resistance into the shunt circuit by means of the hand regulator, and then open the switch. Previous to this, however, it is advisable to increase the voltage at the bus bars to a slight extent, as while slowing down the engine the load upon the outgoing dynamo is transferred to the other dynamo armatures, and the current in their series coils not being increased in proportion the voltage at the bus bars is consequently reduced somewhat.

Dividing Load.—When a number of compound dynamos of different outputs, size, or make are running together in parallel, it frequently happens that all their characteristics are not exactly similar, and therefore the load is unequally distributed amongst them, some being overloaded, whilst others do not take up their proper share of the work. If the difference is small, it may be compensated by means of the field regulator; if large, however, other means must be taken to cause the machines to take up their due proportion of the load. If the series coils of the several dynamos are provided with small adjustable resistances, in the form of german silver or copper ribbon inserted in shunt with the coils, the distribution of the current in the latter may be altered by varying the resistance attached to the individual coils, and thus the effect of the series coils upon the individual armatures in raising the pressure may be adjusted, and the load thus evenly divided among the machines.

CHAPTER X.

INSTALLATION, RUNNING, AND MAINTENANCE OF DYNAMOS.

Essential Features of Modern Dynamos.—In making choice of a dynamo, the voltage and capacity of the machine must be determined by the special requirements of each particular case; there are, however, certain essential features of construction which must appear in a modern dynamo to render it efficient and satisfactory in practical work. In selecting a dynamo in any but the smallest machines —from, say, 5 kilowatts—the iron-clad multipolar type of field magnet should be adopted, and this should further be arranged so that the yoke ring is divided into two parts, horizontally. If the top half is provided with a ring bolt, this facilitates this portion being lifted off, thus enabling easy access being obtained to the armature in case of examination being required for cleaning or repairs. In the case of large size machines it is also preferable to have the field magnet fitted with suitable means for adjusting the armature clearance both horizontally and vertically. The field coils should be wound on formers or spools, arranged so as to be easily removable from their respective pole pieces without disturbing either the windings of the coil itself or its insulation. It will be found that in almost all cases

the drum type of armature will be most satisfactory, and this should be provided with former wound interchangeable coils or built up bar windings. The machine should be provided with not less than two brushes for each collecting point on the commutator, so that sparking is prevented to a large extent, and replacement of the brushes is rendered possible, even when the machine is running. The brush-holders should be mounted on a brush-rocker or ring to enable the brushes to be moved into the best position on the commutator for sparkless collection. The commutator should be built up of hard drawn copper segments, insulated from each other and from the core by selected mica of such quality as will wear evenly with the copper segments. The radial depth of the bars should not be less than one inch, to allow for ample wear, and they should be held in position by suitably shaped micanite washers. The bearings should be of the spherical-seated self-oiling type, and of ample size to ensure cool running, the length of bearing surface being not less than three times the diameter of the shaft. They should be provided with oil rings, arranged for automatic lubrication, and with means to prevent the oil being thrown into the commutator or other parts of the machine. A good finish of the machine generally is desirable, since it is likely to cause greater care being taken to keep it clean and in good order.

Location of Dynamo.—In selecting a suitable position for a dynamo, it should be brought as close as possible to its work in order to reduce the fall of potential or pressure due to the resistance of the mains and also to economise the cost of the latter.

The position of the dynamo should be clean and dry, and the machine should be protected as far as possible from dust and flying particles. Assuming the dynamo to be belt-driven, sufficient distance should be allowed between the engine or counter-shaft and driving pulley and the dynamo for a good "drive," without which the belt will slip or will require straining so tight as to cause heating of the bearings.

Dynamo Foundations.—The first essential for success in dynamo running is to have the machine firmly and securely fixed upon a good and sound foundation; for no dynamo, however well constructed and managed, will run well unless this is the case, the vibration engendered by a bad foundation resulting in sparking at the brushes, and in other evils which greatly tend to reduce the life of the commutator and other parts of the machine. It is also advisable, if the machine is belt or rope driven, to mount it upon a sliding bedplate provided with brackets and tightening screws for aligning and adjusting the tension of the belt while the machine is running. The foundation may be of wood, stone, brick, or concrete. Wood, as a rule, is only used in making foundations of a temporary character, the other materials being used for more permanent foundations.

Brick or Stone Foundations.—In making either brick, stone, or concrete foundations, the excavation should be carried far enough down to secure a good bottom. The foundation, if of brick or stone, should be built up in cement to a suitable height, and a large flat stone cemented on the top. Ordinary lime mortar is quite unsuitable for the purpose of building

dynamo or engine foundations, as the vibration will cause the mortar to disintegrate in the course of time. It will be necessary to build up the foundation, when brick or stone is employed, upon footings; the following approximate rule may be of use in determining the size of footings to be allowed under various conditions: On compact gravel, the spread of footings should be equal to one and a half times the width of foundation; on stiff clay two times the width of foundation. On soft clay it is necessary to make use of a base of concrete under the foundation and footings proper, this being run in so as to project all round the base of the foundation. In the case of small dynamos, it will only be necessary to carry the holes for the holding-down bolts from 6 to 8 inches into the foundation. With large dynamos, however, the holes should be carried as far down as possible, and the holding-down plates, of wrought or cast iron, built in. Underneath each of the plates hand holes should be made, so that the cotters may be inserted into the bolts when these latter are being fixed in position.

Concrete Foundations. — In making concrete foundations, the simplest plan, for small dynamos, is to make a few taper wooden boxes, a few inches square and of suitable length, and nail them on to a template of the base of the machine where the holding-down bolts will come. Having firmly fixed the template, with the boxes in position, the concrete may be run in. When hard, the boxes and template may be removed, leaving holes in the concrete for the holding-down bolts. In the case of large dynamos, the holding-down bolts should be built in at the time

the foundation is made. In this case, the bolts, provided with holding-down plates and narrow taper boxes, or metal tubes of suitable length, are slung in the holes in the template, and the concrete is run in. The bolts being loose in the boxes, are thus capable of a little lateral play while firmly fixed longitudinally. Fig. 85 illustrates diagrammatically this method of making foundations.

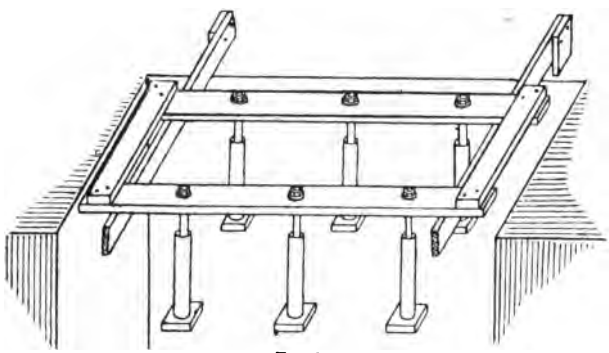


FIG. 85.

Height of Foundations.—It is advisable, in all cases, to carry the top of the foundations of both large and small dynamos to a few inches above the surface of the surrounding ground or floor. The dynamo is thus kept clear of any water which may accumulate. In the case of small dynamos, it will generally be found necessary, in order to keep the belt from coming into contact with the ground, and to enable the brushes to be more conveniently adjusted, to carry the top of the foundation up to from 12 to 24 inches above the surface of the ground.

Erecting Dynamos.—In unpacking and erecting

a dynamo great care should be taken not to injure any part of the machine, and to clean scrupulously from each part any adherent particles of grit, dust, metal chips, waste, &c. Before proceeding to erect the machine, the blue print, usually supplied, should be carefully studied, so that each part is placed and securely fixed in its correct position. If the engine room is provided with a travelling crane no difficulty will be experienced in erecting the heavy parts, but if this is absent it will be necessary to erect temporary gear composed of timber beams and scaffold poles, in order to lift the parts into their places, wooden rollers being used for moving the parts from place to place on the floor. Fig. 86 shows a temporary gear of the kind referred to, often used for erecting the heavy parts of a dynamo or other machine. As will be seen it consists of two poles, the ends of which are sunk for a little distance into the ground, or otherwise prevented from slip; the poles may be fixed at any desired angle by means of the anchor ropes, which are securely fastened to the anchor stake driven or sunk into the ground some distance from the poles. In fixing either direct or belt-driven dynamos, it will first be necessary to ascertain, with a spirit-level and long straight-edge, whether the top of the foundation is level and true. If this is found to be the case, the holding-down bolts should be dropped into the holes in the foundation, if they are not already built in, and the dynamo bedplate carefully placed thereon, the ends of the bolts being passed through the holes in the bedplate and secured by a few turns of the nuts. The fitting into place of the various parts should then be proceeded with. In handling the field magnets,

ropes should not be passed round the windings of the field coils for the purpose of lifting under any circumstances; if the poles are supplied separately, the contact faces should be carefully cleaned and lightly oiled with a rag before being fixed in place. The

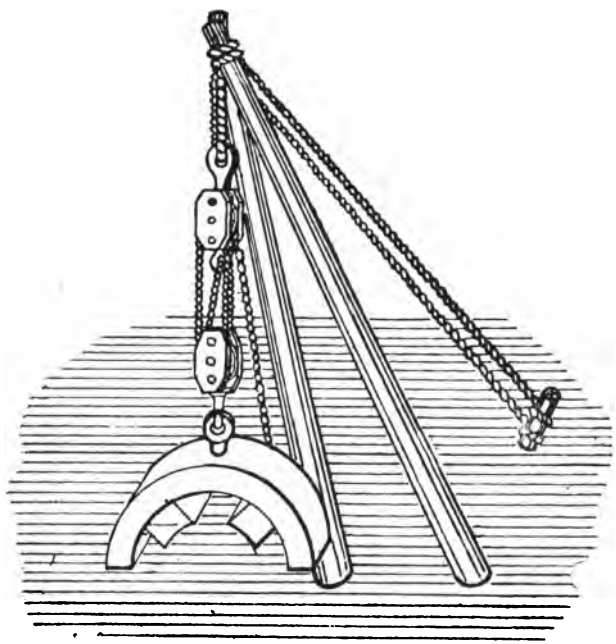


FIG. 86.

field magnet frame in both bi-polar and multipolar machines must be concentric with the armature, *i.e.*, the axes should coincide so that the air-gap will be the same all the way round; this should be carefully tested, turning the armature round into different

positions in order to eliminate errors caused by the armature not being truly wound. If the air-gap is not the same all round the armature, the machine will be magnetically unbalanced, and will tend to spark badly even on light loads. The armature must also be set so that the centre line of the armature, horizontally, coincides with the centre of the poles, although sometimes this will be different, as some makers allow a little wider air-gap at the bottom on new machines, so that when the bearing bushes get worn down the armature becomes central. In order that the field frame may be conveniently adjusted in relation to the armature, it is usual in the best machines, to provide the magnet feet with special adjusting screws, by means of which the air-gap may be adjusted in any direction. The armature should be handled with the greatest possible care in order not to injure the windings and their insulation, as well as the commutator and shaft. A slight blow to the commutator may cause one or more of the segments to be driven in, perhaps necessitating an expensive repair being required. When placed on the ground a pad of cloth should be interposed, but it is a better plan to suspend it with the shaft in a wooden trestle or frame. When being lifted it should be slung from the shaft, the lifting tackle being kept out of contact with the windings and commutator. Fig. 87 shows a convenient form of sling for handling armatures and their shafts. When the armature is fitted into place, the dynamo should then, if belt-driven, be carefully aligned with the driving pulley or fly-wheel. In order that the belt may run true on the pulleys, it is needful that a straight line

joining the two pulleys should pass through the centre of the face of the driving pulley and the centre of the face of the dynamo pulley. To effect this, when both pulleys are equal in width across the face, a fine cord is stretched perfectly straight from one pulley to the other across the edges lying in one plane; then, by adjusting the position of the

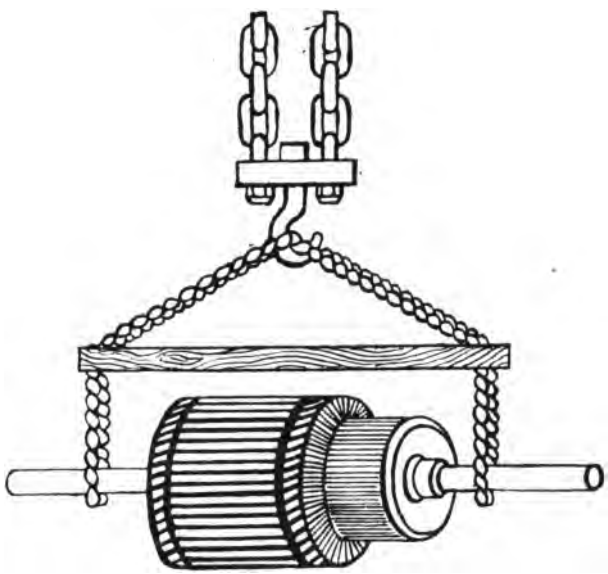


FIG. 87.

dynamo, the cord can be made to touch the two edges of one side of the driving pulley and the two edges of one side of the dynamo pulley, when the pulleys will be truly aligned, and the machine set square with the driving shaft. If one of the pulleys is wider across the face than the other, the difference

should be carefully noted, and allowance made when lining off. Too much attention cannot be paid to getting the pulleys truly aligned, as the belt is liable to drop off when the machine is started if this is not the case. The dynamo bedplate, and also, if possible, the armature shaft, should next be carefully and finally tested with a spirit-level, and if not found truly level, the machine should be packed up until perfectly level either way. Having carefully aligned the pulleys and levelled the machine, it should next be grouted with thin cement. This is effected by arranging a wall of bricks or a few wooden battens around the bedplate of the machine, leaving a few inches clear all round, and stopping up all holes with clay or stiff cement. Thin cement is then run in until the holding-down bolt-holes are full, and the cement has risen to the level of the underside of the bedplate. When the cement is set hard, the bricks or wooden battens may be removed, and the edges of the foundation trimmed off, and the nuts of the holding-down bolts screwed up tight and the machine securely fixed.

Dynamo Belting.—The dynamo, if belt-driven, should be provided with a driving belt of a size suitable for the pulley on the machine, the rule being to allow a width of pulley one-fourth greater than the width of the belt. The belt should not be too heavy and should be soft and pliable. It should be of just sufficient tightness to prevent slip at full load, and should be fastened with a butt joint, or better, made endless and sewn with a long scarfed joint; a lapped joint will cause vibration and variation of the voltage, with consequent flickering of the lamps, if the dynamo is used for lighting purposes; it is also

liable to cause sparking of the machine. The crowns of the driving and dynamo pulleys should be of the same radius, as otherwise the belt will not run true. The ratio between the diameters of the pulleys should not exceed 6 to 1; if the required speed cannot be obtained on the dynamo pulley at or below this ratio, it will be necessary to arrange a countershaft. The distance apart of the pulleys depends upon the ratio. For pulleys having diameters of 2 to 1 the distance between centres should not be less than 8 feet; if 3 to 1, 10 feet; if 4 to 1, 12 feet; if 5 to 1, 15 feet. The exact amount of power that a given belt is capable of transmitting is not very definite. The ordinary rule is that single belting will transmit $1\frac{1}{2}$ horse-power for each inch of width when travelling at a speed of 1,000 feet per minute. If the speed be greater or less, the power is correspondingly increased or decreased. This rule is based upon the condition that the belt is in contact with the pulley around one-half (180°) of the circumference of the pulley, which is usually the case, except in very short drives, which are not to be recommended. If the arc of contact is less than a half circle, the power transmitted is less in the following proportion: arc of contact of 135°, or $\frac{3}{8}$ of the whole circumference, gives .84, while 90° gives only .64 of the power derived from a belt contact of 180°. The following table gives the horse-power that different leather belts will transmit per inch in width at various speeds:—

Horse-Power that Different Leather Belts will Transmit per Inch in Width at Various Speeds.

Velocity of Belt per Minute.	Kind of Belts.								
	Best Oak-tanned Belts.			Best Link or Chain Belts.					
	Single Belts.	Light Double Belts.	Heavy Double Belts.	⅜	½	⅝	¾	⅞	1
	Horse-Power they will Transmit.								
Feet.									
100	.15	.21	.27	.13	.15	.17	.20	.24	.27
200	.30	.42	.55	.25	.29	.35	.40	.47	.55
300	.45	.64	.82	.38	.44	.52	.60	.71	.82
400	.61	.85	1.09	.51	.58	.69	.80	.95	1.09
500	.76	1.06	1.36	.64	.73	.86	1.00	1.18	1.36
600	.91	1.27	1.64	.76	.87	1.04	1.20	1.42	1.64
700	1.06	1.49	1.91	.89	1.02	1.21	1.40	1.65	1.91
800	1.21	1.70	2.18	.92	1.16	1.38	1.60	1.89	2.18
900	1.36	1.91	2.45	1.05	1.31	1.55	1.80	2.13	2.45
1000	1.51	2.12	2.73	1.27	1.45	1.73	2.00	2.36	2.73
1100	1.67	2.33	3.00	1.40	1.60	1.90	2.20	2.60	3.00
1200	1.82	2.55	3.27	1.53	1.75	2.07	2.40	2.84	3.27
1300	1.97	2.76	3.55	1.65	1.89	2.25	2.60	3.07	3.55
1400	2.12	2.97	3.82	1.78	2.04	2.42	2.80	3.31	3.82
1500	2.27	3.18	4.09	1.91	2.18	2.59	3.00	3.55	4.09
1600	2.42	3.39	4.36	2.04	2.33	2.76	3.20	3.78	4.36
1700	2.58	3.61	4.64	2.16	2.47	2.94	3.40	4.02	4.64
1800	2.73	3.82	4.91	2.29	2.62	3.11	3.60	4.25	4.91
1900	2.88	4.03	5.18	2.42	2.76	3.28	3.80	4.49	5.18
2000	3.03	4.24	5.45	2.55	2.91	3.45	4.00	4.73	5.45
2100	3.18	4.45	5.73	2.67	3.05	3.63	4.20	4.96	5.73
2200	3.33	4.67	6.00	2.80	3.20	3.80	4.40	5.20	6.00
2300	3.49	4.88	6.27	2.93	3.35	3.97	4.60	5.44	6.27
2400	3.64	5.09	6.55	3.05	3.49	4.15	4.80	5.67	6.55
2500	3.79	5.30	6.82	3.18	3.64	4.32	5.00	5.91	6.82
2600	3.94	5.52	7.09	3.24	3.78	4.49	5.20	6.15	7.09
2700	4.09	5.73	7.36	3.28	3.85	4.66	5.40	6.38	7.36
2800	4.24	5.94	7.64	3.31	3.86	4.73	5.60	6.62	7.64
2900	4.39	6.15	7.91	3.32	3.87	4.78	5.80	6.85	7.91
3000	4.50	6.36	8.18	3.31	3.86	4.75	5.97	7.09	8.18
3100	4.60	6.58	8.45	3.30	3.85	4.73	5.96	7.33	8.45
3200	4.69	6.79	8.70	3.28	3.82	4.71	5.94	7.37	8.73
3300	4.77	7.00	8.86	3.24	3.77	4.70	5.92	7.35	8.88
3400	4.84	7.21	8.96	3.19	3.71	4.64	5.87	7.32	8.86
3500	4.90	7.31	9.06	3.13	3.61	4.50	5.78	7.26	8.80
3600	4.95	7.40	9.16	3.05	3.50	4.37	5.67	7.16	8.73
3700	4.99	7.48	9.24	2.96	3.39	4.26	5.55	7.01	8.58
3800	5.03	7.54	9.29	2.84	3.28	4.15	5.41	6.87	8.41
3900	5.06	7.60	9.34	2.72	3.13	4.02	5.20	6.70	8.27
4000	5.08	7.64	9.37	2.58	2.95	3.84	5.01	6.48	8.04

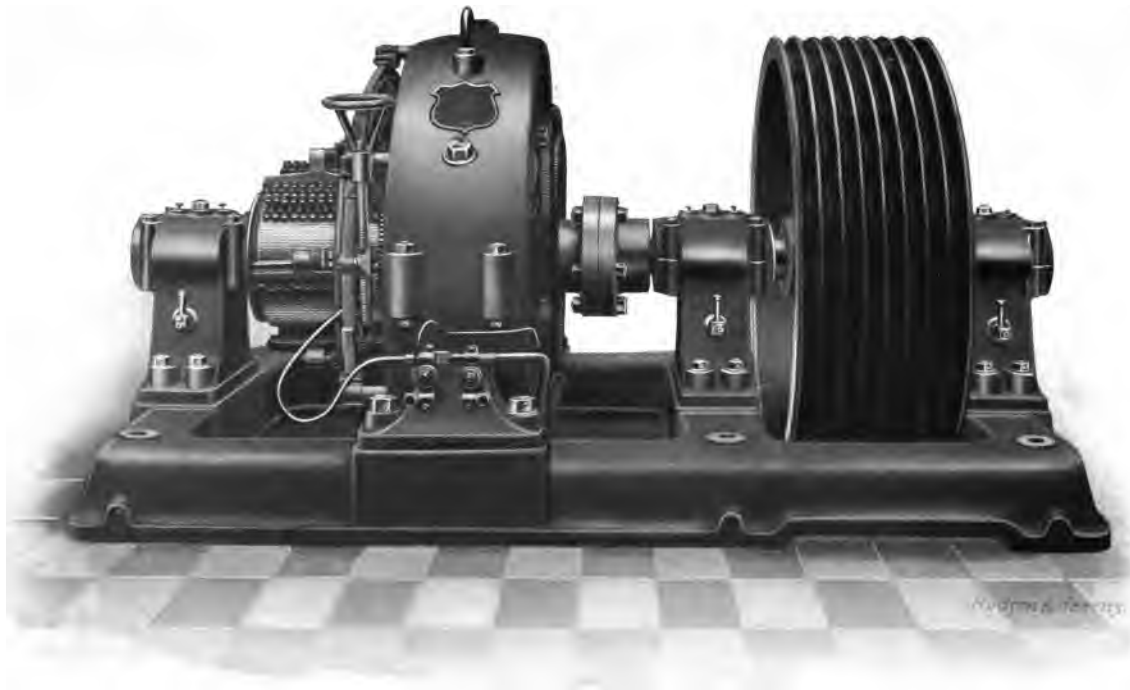
Rope Driving.—Dynamos of medium size are now frequently adapted for rope driving, this method of driving being much cheaper both in first cost and in maintenance than belt driving. The most economical speed for ropes is from 4,500 feet to 5,000 feet per minute, while the least size of pulley should, wherever possible, not be less than thirty times the diameter of the rope. The following table gives the horse-power transmitted by good cotton driving ropes at various speeds:—

Horse-Power that Good Cotton Driving Ropes will Transmit at Various Speeds.

Speed in Feet per Minute.	Diameter of Ropes in Inches.								
	1	1⅛	1¼	1⅜	1½	1⅝	1¾	1⅞	2
	Horse-Power Transmitted.								
2500	10.8	13.4	16.7	20.5	24.3	28.5	33.2	38.1	43.4
2600	11.1	13.9	17.2	20.8	25	29.4	34.1	39.4	44.7
2700	11.4	14.3	17.7	21.7	25.7	30.2	35.3	40.6	46
2800	11.8	14.7	18.2	22.3	26.4	31	36.2	41.7	47.3
2900	12.1	15.1	18.7	22.9	27.1	31.9	37.2	42.8	48.6
3000	12.3	15.4	19.1	23.4	27.8	32.6	38.1	43.8	49.5
3100	12.5	15.7	19.5	24	28.4	33.4	39	44.8	50.6
3200	12.9	16.1	19.9	24.5	29	34	39.9	45.8	52
3300	13.2	16.5	20.3	25	29.6	34.8	40.8	46.8	53.2
3400	13.4	16.7	20.6	25.5	30.1	35.4	41.6	47.7	54.3
3500	13.6	16.9	20.9	26	30.6	36.2	42.3	48.6	55.2
3600	13.9	17.1	21.2	26.4	31.1	36.5	43	49.5	56
3700	14.1	17.3	21.5	26.8	31.5	37.1	43.6	50.2	56.8
3800	14.2	17.5	21.7	27	31.9	37.5	44.2	50.8	57.6
3900	14.4	17.7	21.9	27.3	32.2	37.9	44.8	51.4	58.2
4000	14.5	17.8	22.1	27.5	32.6	38.4	45.3	51.9	58.9
4100	14.6	17.9	22.3	27.8	32.9	38.7	45.8	52.4	59.6
4200	14.7	18	22.5	28	33.1	39	46.3	52.8	60.3
4300	14.8	18	22.6	28.1	33.3	39.3	46.6	53.2	60.6
4400	14.9	18.1	22.7	28.2	33.4	39.6	46.8	53.5	60.9
4500	15	18.1	22.7	28.3	33.5	39.7	47	53.8	61.2
4600	15.1	18.1	22.7	28.4	33.6	39.7	47.2	54	61.4
4700	15.1	18.1	22.6	28.4	33.7	39.8	47.4	54.2	61.5
4800	15.1	18	22.6	28.5	33.7	39.8	47.5	54.2	61.5
4900	15	18	22.5	28.5	33.7	39.9	47.6	54.3	61.6
5000	15	17.9	22.4	28.4	33.6	39.8	47.5	54.3	61.5

Dynamo belts or ropes should always be arranged so that the driving or tight side is at the bottom and the slack side on top. This gives a better grip of the belt or rope on the pulley, and prevents the belt or rope sagging and striking the floor while the machine is running. In measuring for a belt or rope, the dynamo should be moved in its sliding bedplate, so as to make the distance the shortest in order to allow for the belt or rope stretching, which it will do to a considerable extent while working, if new. The exact length of belting required may be ascertained by means of a wire, stretched from one pulley to the other.

Preliminary Examination of Machine—When the machine has been securely fixed, and previous to the first starting, the whole of the machine should be carefully examined to see that all parts are in good order, and have not been damaged. The field magnet circuit should first be inspected to see that none of the wires or connections have been broken or are loose, and that the coils are correctly coupled up. The caps of the bearings should next be taken off, and these and the journals carefully cleaned from all grit and dirt. They should then be oiled, and the caps replaced and screwed up with the hand only. The gaps between the outer surface of the armature and the polar faces should be examined in order to ascertain whether any foreign body, such as a small screw or nail, has lodged therein. If such is the case, it should be carefully removed with a bit of wire. If guard plates are provided for protecting the armature windings these should also be removed, and the windings carefully inspected by slowly rotating the armature, to see that they are not damaged, and



[*To face page* 168.

ROPE-DRIVEN DYNAMO.

that the insulation is perfect. The armature should then be finally rotated by hand to see that it revolves freely, and that the bearings are securely fixed. The commutator and brushes should next receive attention,—the commutator, to see that it is not damaged in any way through one or more of the segments being knocked in, or the lugs being forced into contact with one another; and the brush-holders and brushes, to see that the latter are clean and make good contact with the brush-holders or flexible leads, and the former to see that they work freely on the spindle, and that the hold-off catches work properly. In the subsequent working of the dynamo it will of course not be necessary to follow the whole of these proceedings every time the machine is started as it is extremely unlikely that the machine will be damaged from external causes whilst working without the attendant being aware of the fact. Having ascertained that the machine is not injured in any way, and that the armature revolves freely, the adjustment of the brushes should next be proceeded with.

Adjustment of Brushes.—The adjustment of the brushes upon the commutator requires careful attention if sparking is to be avoided. The points upon the commutator at which the tips of the brushes, carried by opposite arms of the rocker, bear upon the commutator, should be, in bi-polar dynamos, at opposite extremities of a diameter. In multipolar dynamos the positions vary with the number of poles and the nature of the armature winding. In order to facilitate the correct setting of the brushes upon the commutator, *setting* marks are usually cut in the collar of the commutator next to the bearing. In

bi-polar dynamos, these setting marks divide the circumference of the commutator into equal parts. In adjusting the brushes, the tips of all the brushes carried by one arm of the rocker are set in correct line with the commutator segment marked out by one setting mark, and the tips of the brushes carried by the other arm or arms are set in correct line with the segments marked out by the other mark or marks. If one or more brushes in a set are out of line with their setting mark, it will be necessary to adjust the brushes up to this mark by pushing them out or drawing them back, as may be required, afterwards clamping them in position. When adjusting the brushes the armature should always be rotated if possible, so that the setting marks are horizontal. The rocker can then be rotated into position, and the tips of both sets of brushes conveniently adjusted to their marks. In those brush-holders provided with an index or pointer for adjusting the brushes the setting marks upon the commutator are absent, the length of the pointer being so proportioned that when the tips of the brushes are in line with the extreme tips of the pointers, the brushes bear upon the correct positions on the commutator. In the absence of both setting marks and pointers to the brushes, it will be convenient to divide the commutator into a number of equal parts by counting the segments and dividing the total by the number of poles of the field magnet, afterwards punching suitable marks on the collar of the commutator by means of a centre punch, or a suitable template may be made of sheet metal to enable the brushes to be adjusted to their correct positions on the commutator.

Bedding Brushes.—Having adjusted the brushes to their correct positions upon the commutator, their tips or rubbing ends should next be examined, whilst in position, to see that they bed accurately on the surface of the commutator. In many instances it will be found that this is not the case, the brushes sometimes bearing upon the point or toe, and sometimes upon the heel, so that they do not make contact with the commutator throughout their entire thickness and width. The angle of the rubbing ends will therefore need to be altered to make them lie flat, otherwise violent heating of the brushes and commutator will ensue. In those dynamos provided with armatures wound with two or more separate and distinct windings arranged in parallel (as referred to in page 53), it is most important that the brushes bed accurately on the commutator and that they span the requisite number of commutator bars. If this is not the case the circuits of one or other of the armature windings will be broken as it leaves the brushes and violent heating and sparking will result.

In the case of metallic brushes, when these do not bed properly upon the commutator, and filing has to be resorted to in order to alter the angle of the brush tips or ends, it will be found necessary to fix the brush in a holder or filing clamp, in order that the correct angle may be conveniently obtained. This, as a rule, is supplied with the machine, and consists of two pieces of metal, both shaped at one end to the correct angle (usually 45°), to which the brushes must be filed. One of the pieces of metal (the back part) has a groove sufficiently large to accommodate the brush, which is clamped in position by the other piece

of metal and a pinching screw. If the clamp is not supplied, a convenient substitute can be made out of two pieces of wood about the same width as the brush. Fig. 88 shows a convenient arrangement of this description. It is made of hard wood, such as birch or teak for preference. One end of each piece of wood is sawn to the correct angle, and the brush is placed between the two. In filing, the brush is fixed in the clamp, with the toe or tip projecting slightly over the edge of the clamp, and the latter being fixed in a vice, the brush is filed by single strokes of a smooth file made outwards, the file being raised from contact with the brush when making the back stroke.

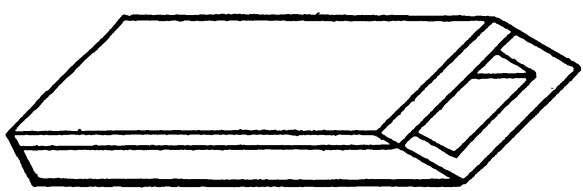


FIG. 88.

Any loose strands of wire which may remain after filing can be removed by means of a pair of scissors or snips, and the edge trimmed off quite square. Carbon brushes, which are now very extensively used, being hard and unyielding—unlike metallic brushes—require bedding very accurately to the curvature of the commutator in order to obtain sparkless running. The best method of bedding these brushes is to slip a piece of medium glass or emery cloth or paper between the brushes and the commutator, with the rough surface of the paper outwards, of course, and move it backwards and forwards under the brushes

until their ends are accurately ground down to the curvature of the commutator. During this operation the paper or cloth should be kept drawn down close against the surface of the commutator to prevent the edges of the brushes being chamfered off and the effective area of contact surface of the brush reduced. A most effective and expeditious method of bedding either metallic or carbon brushes is to bind a sheet of glass or emery cloth around the commutator, holding it in place by means of string or wire bound at the edges. The brushes are then lowered on to the commutator, adjusting the tension of the brush-holder springs so that the brushes bear with a moderately strong pressure upon the emery or glass cloth or paper. The machine is then kept running so that the armature revolves slowly, until the ends of the whole of the brushes have been ground down to the correct curvature. This method of bedding brushes is more particularly adapted for small-sized machines as the small sheets of emery or glass paper or cloth may be readily obtained; but it is equally applicable for large size commutators if the glass or emery cloth can be obtained in rolls, or a number of small sheets may be glued together at their edges so as to encircle the circumference of the commutator. In this latter case, care should be taken that the edges of the emery or glass cloth are arranged so as not to catch in the edges of the brushes while revolving. It is most important, while bedding the brushes in the manner referred to, that the carbon or metal dust given off does not get into the commutator connections or armature windings or short-circuiting will result. It is a good plan, to prevent this occurring, to cut some

sheets of paper to shape and fix them to the commutator lugs—a few dabs of shellac will hold them in place. When the brushes have been finally bedded down, the mica insulation between the commutator segments should be carefully examined in order to ascertain if any small fragments of carbon or copper have become lodged between the segments, thus causing short-circuiting, when, if this happens, they should be scraped out. In a new machine, or in an old one, when the brushes have been bedded down in the manner referred to, the commutator should be cleaned up with a clean rag dipped in paraffin until it no longer picks up further carbon dust, and then thoroughly wiped over with a clean dry rag. It is always advisable, after bedding the brushes in this manner, to run the machine without load for some time in order to allow the brushes to seat themselves down and make good contact with and burnish the commutator, as good commutation cannot be expected unless at least 75 to 80 per cent. of the brush surface is in contact. For a good quality carbon brush the current density to be used may be taken at from 30 to 40 amperes per square inch of sectional area, this varying with the quality of the carbon and conditions of working. The expression for determining the contact surface of ordinary carbon brushes is $0.9\ C \div \sqrt{V}$ square inches, where C is the current in amperes and V the peripheral velocity of the commutator in feet per minute. When these brushes are employed care should be taken that the quality of the carbon is suited to the speed and voltage of the machine. For low voltage machines, working at 100 to 150 volts, a high conductivity brush is required,

having a fine close grain and low friction coefficient. For voltages of from 200 volts and upwards a high resistance quality of carbon is more suitable.

Pressure of Brushes upon Commutator.—Having ascertained that the brushes are correctly placed and bedded upon the commutator, it remains to adjust their pressure upon the latter. This is effected by regulating the tension of the springs provided for the purpose upon the brush-holders. The tension of the springs should be just sufficient to cause the brushes to make a light yet reliable contact with the commutator. The contact must not be too light, otherwise the brushes will vibrate, and thus cause sparking; nor must it be too heavy, or they will press too hard upon the commutator, grinding and scoring and wearing away the latter and themselves to an undesirable extent, and, moreover, giving rise to a great heating and sparking. The correct pressure is attained when the brushes collect the full strength of current without sparking, while their pressure upon the commutator is just sufficient to overcome any ordinary vibration due to the rotation of the commutator.

Adjusting Lubricators.—Sight feed lubricators, which were formerly fitted to most dynamos, have now given place to automatic lubrication of the revolving ring type as described in Chapter V. In well-designed arrangements of this description, practically no attention is required, beyond an occasional inspection to see that the rings work properly, and that they and the oil passages, cut in the liners or bushes, are not clogged with dirty oil, so that the needful circulation of lubricant is kept up. In ordinary

circumstances, the oil will require renewal at intervals varying from two to four weeks.

Starting Dynamos.—Having attended to the above preliminaries, and having cleared all keys, spanners, bolts, &c., out of the immediate neighbourhood of the machine, and having raised the brushes from contact with the commutator by means of the hold-off catches, the dynamo may be started and allowed to run light. Whilst thus running, the bearings should be tested from time to time to ascertain if they heat unduly, and an opportunity is also afforded, while the dynamo is thus running, for cleaning the commutator, if this is dirty, with fine glass paper, afterwards wiping clean with a linen rag. The connections of the machine and external circuits should be verified, and all terminals, &c., cleaned and examined. If found correct, the brushes should be let down on to the commutator, and their tips adjusted by rotating the rocker into the neutral points. The tips of the brushes carried by one arm of the rocker will, in bi-polar dynamos with vertical field magnets, bear exactly upon the top or highest point of the commutator, while the tips of those carried by the other arm will bear exactly upon the bottom or lowest point of the commutator. In other types of machines, the positions for the brushes will vary according to the class or form of the field magnet and the system of armature winding. The positions of the brushes in most of the types of dynamos in common use are illustrated in Figs. 21 to 28. If the machine is compound or shunt wound, all switches controlling the external circuits should be opened, as the machine excites best when this is the case; and when the machine is provided

with a rheostat or hand regulator and resistance coils, these latter should all be cut out of circuit, or short-circuited, until the machine excites, when they can be gradually cut in as the voltage rises. When the machine is giving the correct voltage, as indicated by the voltmeter or pilot lamp, the machine may be switched into connection with the external or working circuits. When the machine is series wound, it is absolutely necessary to have the external circuit closed, otherwise a closed circuit will not be formed through the field magnet windings, and the machine will not excite. In starting up a new machine for the first time, it is advisable to exercise caution, in case some part may have received injury which is not apparent to ordinary observation; or some part may not be securely fastened. The shaft may also show a tendency to seize and score the journals or liners, consequently the machine should be kept running at a slow speed for some hours, and in any case the full load should not be switched on for some considerable time. The windings may be damp and require drying, in which case the machine should be kept running at a much lower voltage than the normal until all moisture has been driven off. If the machine should be started at full speed immediately, thus generating the full voltage, and any considerable degree of moisture exists in the windings, the chances are that one or more of the coils will heat up to such an extent that the insulation will be injured or even destroyed. On large new machines, more especially those having commutator split spiders, or sectional clamping rings, it may be necessary to tighten up the commutator from time to time. When

this has been done it should be frequently cleaned up with the burnisher and glass paper, and during the first month or so the segmental rings should be watched and kept tight until the commutator bars get a firm bedding. It is advisable to do this tightening after a good long run when the machine is hot; if done when the machine is cold there is a liability of the expansion of the copper segments when hot, causing the iron or steel clamping bolts to be broken, since the coefficient expansion of copper is about twice that of iron, and an enormous force is exerted by the copper segments when expanding owing to the heat.

Attention to Dynamo.—When the machine is started and at work, it will need a certain amount of attention to keep it running in a satisfactory and efficient manner. The first point to which attention should be paid is the adjustment of the "lead" of the brushes. If this is neglected, the machine will probably spark badly, and the commutator and brushes will constantly require filing and trimming. The "lead" is the term applied to the slight forward movement which it is found necessary to give to the brushes of most dynamos in order to avoid sparking with an increase of load. This lead in all good dynamos is very small, and varies with the load and class of machine. The best lead to give to the brushes can in all cases be found by rotating the rocker and brushes in either direction to the right or left of the neutral points, until sparking commences increasing with the movement. The position midway between these two points is the correct position for the brushes, for at this position the least

sparking occurs, and it is at this position that the brushes should be fixed by clamping the rocker. In series dynamos giving a constant current, such as for arc lamps in series, the brushes require practically no lead. In shunt and compound dynamos the lead varies with the load, and therefore the brushes must be rotated in the direction of rotation of the armature with an increase of load, and in the opposite direction with a decrease of load. In cases where the dynamos are subjected to a rapidly varying or fluctuating load, it is of course not possible to constantly shift the brushes as the load varies, therefore the brushes should be fixed in the positions where the least sparking occurs at the moment of adjustment. In those dynamos provided with commutating poles, correctly designed, the lead is entirely absent, and no attention is therefore needed for this adjustment of the brushes. If at any time very violent sparking occurs, which cannot be reduced or suppressed by varying the position of the brushes by rotating the rocker, the machine should be shut down at once, otherwise the commutator and brushes are liable to be destroyed, or the armature burnt up. This especially refers to high tension machines. As soon as any abnormal sparking is seen at the commutators of such machines, their speed should be at once reduced, and the commutator cleaned up, the brushes readjusted, and the cause of the sparking ascertained. Another very important point to be looked to is the lubrication of the machine. The lubricators should be inspected from time to time, to see that they feed the lubricant properly, and that none of the waste oil passages are clogged. The oil

should on no account be allowed to get on to the commutator or brushes, or into the windings of the armature, as it is liable to cause sparking at the brushes, and to destroy the insulation of the armature. In filling the lubricators, oil cans made of some non-magnetic material such as copper, brass, or zinc, should always be used. If iron cans are used, they are liable to be attracted by the field magnets, and thus possibly catch in the armature, and destroy the insulation of the latter. The bearings, and also the field magnet coils, should be tested at intervals, to see that they do not become unduly heated. When testing the temperature of low tension machines, the hand may be used as a guide for judging when the machine is running at a safe temperature. If the heat of any portion can be easily borne by the naked hand, it may be taken that the temperature of the machine is within safe limits. In the case of high tension machines, however, the naked hand cannot be brought with safety into contact with any portion of the machine, and therefore the only way to ascertain if the windings or other electrical parts are at a safe temperature is to apply a thermometer. It may be taken as a safe rule that no part of a working dynamo should have a temperature of more than 80° Fahr. above that of the surrounding air. Hence, if the temperature of the engine-room is noted before applying the thermometer to the machine, it can at once be seen if the latter is working at a safe temperature. In taking the temperature, the bulb of the thermometer should be wrapped in a woollen rag. The screws and nuts securing the different connections and tables should be examined occasionally,

as they frequently work loose through the vibration. In attending to dynamos generating a pressure of over 300 volts, rubber gloves should always be worn. Where these are not available the safest plan is not to touch any conductor whatever with the naked hand when the current is on, but it must always be remembered that the current may be present when not expected, due to an accidental contact with some live wire or change of connections. A dry stick should be used instead of the bare hand when desirous of ascertaining if the brushes of a running dynamo require readjusting, or if any of the connections are loose.

Attention to Brushes and Commutator.—The brushes and commutator are the most troublesome parts of a dynamo, and require most attention. To keep them in a satisfactory working condition, the main thing to be guarded against is the production of sparking at the brushes, and this is especially important in the case of large multipolar dynamos, which are provided with commutators, the renewal of which is both troublesome and costly. If care be taken in the first instance to properly adjust the brushes to their setting marks, and their pressure upon the commutator, and afterwards to attend to the lead as the load varies, so that little or no sparking occurs, and to keep the brushes and commutator free from dirt, grit, &c., and excessive oil, the surface of the commutator will assume a dark burnished appearance, and all wear will practically cease. Under these circumstances the commutator will run cool, and free from sparking, and will give very little trouble. In order to maintain these conditions it will only be necessary to see

that the brushes are properly trimmed and fed forward to their setting marks, as described above, as they wear away, and that the commutator is occasionally polished with the finest glass paper. If, on the other hand, the pressure of the brushes upon the commutator is too great, or their adjustment is faulty, or the commutator is allowed to get into a dirty condition, sparking will inevitably result, and, if not at once attended to and remedied, the brushes will quickly wear away, and the surface of the commutator will be destroyed. If this condition of things is allowed to continue, matters will rapidly get worse. In the earlier stages, the surface of the commutator will become roughened or scored, resulting in jumping of the brushes, and increased sparking; in the later stages, the commutator will become untrue and worn into ruts, and owing to the violent sparking which takes place through this circumstance, the machine will quickly be rendered useless for practical purposes. When once started, the only way to remedy this condition of things is to repolish the commutator and readjust the brushes, as directed above. If the commutator is merely scored, a smooth file applied while the armature is revolving, with a final polishing with coarse and fine glass paper, will generally put things into a satisfactory condition. If, however, the commutator is worn into deep ruts, or is untrue, nothing short of re-turning or grinding the commutator, will make a good job of it. When carbon brushes are used, a little extra special attention should be given in keeping the commutator perfectly clean, true, and smooth, otherwise it is liable to heat up through short circuits, caused by carbon dust lodging

between the segments. When carbon brushes are working properly, the fact is indicated by a uniform greyish tinge being imparted to the commutator, with a total absence of heating or sparking of any description. If the surface of the commutator assumes a mottled or streaky appearance, accompanied by small sparks flashing from segment to segment, it is advisable to slow down the machine and clean up the commutator at once. When either metal or carbon brushes are used, the surface of the commutator is bound in course of time to undergo a certain amount of wear, even when the greatest care is taken to reduce sparking. In order to prevent this wear giving rise to ruts or ridges upon the surfaces of the commutator, it is advisable to shift the brush-holders and brushes upon the rocker arm, if this is possible, from time to time. The unequal wear of the commutator may also be prevented by so arranging the brushes carried by one arm of the rocker that they cover the gaps between the brushes carried by the other arm of the rocker. The armature spindle or shaft is also given a little end play in some cases, in order to prevent this grooving.

Trueing Commutator.—When the commutator gets into such bad condition that polishing with glass or emery cloth fails to restore it to its original smooth and burnished appearance, other methods must be adopted in order to render it satisfactory. If only slightly scored or rough, filing may be resorted to, but this method has the disadvantage that if some bars of the commutator happen to be higher or lower than others, the commutator is liable to be rendered eccentric by the filing process. Under these circumstances a commutator burnisher of the

pattern shown in Fig. 89 is to be preferred. This appliance consists essentially of a strip of stout flexible sheet metal, provided with a handle and clip. In operation a strip of emery or glass paper or cloth about the same width as the flexible back is cut, and one end inserted under the clip at the front end. It is then turned back under the flexible backing and applied to the commutator of the machine, which is run at a moderate speed with the brushes lifted. The flexible backing is made in such a manner that it readily adapts itself to the curvature of the commutator, but will not fall into any depression on the surface. Thus the whole surface is evenly and truly ground down to any degree of coarseness required, and afterwards polished with fine emery or glass paper or cloth. Another method of trueing the commutator, which is much used in America, is to "stone" it with a brick or block of fine sandstone or carborundum. These blocks measure about 4 to 6 inches wide by 8 to 10 inches long, and are made to fit the curvature of the commutator. The block is applied to the commutator while the machine is running in a somewhat similar manner to that already described. A stone used in this way will usually reduce high bars, as it will not follow irregularities in the commutator. After being stoned, a

FIG. 89.

sheet of fine glass paper should be used to polish up the commutator. This method saves considerable time and money, and ensures sparkless commutation, but care must be taken to remove any particles of copper which may become embedded in the grinding surface of the block, otherwise the commutator may get badly scored or fluted. The armature windings and the spaces between the commutator lugs must be protected from the grit, carbon, or copper dust, given off during the process of stoning. It is a good plan before commencing work to fix some sheets of paper, trimmed to shape, on to the commutator lugs to prevent the dust gaining access to the armature windings. The above methods of trueing the commutator are more particularly suited for the removal of small defects existing in the surface of the commutator, such as scorings and ruts formed by the brushes when not properly adjusted. They are of no use whatever when the commutator becomes bodily eccentric, either through being insecurely fixed on the armature shaft or through unequal wear, usually caused by loose bearings or bearing pedestals. When this occurs the only remedy is to turn up the commutator in the lathe or grind it down with the aid of an emery wheel.

In re-turning the commutator, the armature should first be carefully taken out of the armature chamber, avoiding knocks or blows of any kind. The whole of the windings should then, in order to prevent any particles of metal finding their way on to the surface of the armature at the time the commutator is being turned, be entirely wrapped in calico or canvas before the armature is put into the lathe. The armature

should on no account be rolled upon the floor, or subjected to blows or knocks while being put into the lathe; the winding is liable to be ruined if this takes place. In re-turning the commutator, a sharp-pointed tool should be used with a very fine feed. A broad-nosed tool ought not to be used, as it is liable to burr over the segments. As the bars have a tendency to spring when passing under the tool, the cutting speed should not exceed 90 feet per minute. Light cuts only should be taken, as the tool is liable to dig in. After turning, the commutator should be lightly filed up with a dead-smooth file, and finally polished with coarse and fine emery cloth. After the commutator has been turned and polished, the insulation between the segments should be lightly scraped with the tang of a small file to remove any particles or burrs of metal which may be likely to short circuit the commutator. The points where the armature wires are soldered to the lugs should also be carefully cleaned with a brush from any adherent copper dust, and should then receive a coat or two of shellac varnish. While the commutator is being turned, care should be taken that the setting marks for the adjustment of the brushes are not turned out if these are present. The same care should be used in putting the armature back into the armature chamber as was used in taking it out, otherwise the insulation is liable to be seriously damaged.

Lubricant on Commutator.—A great diversity of opinion exists as to whether anything of the nature of a lubricant should be used on the commutator, but in most cases it will be found that a little lubricant of some kind is absolutely necessary in order to prevent

cutting of the commutator by the brushes. The quantity of lubricant so used should be very small—a few drops smeared upon a piece of clean rag and applied to the commutator while running being quite sufficient. If an excess of lubricant is present on the commutator either through accident or design it is liable to carbonise owing to the excessive sparking and great heat developed through the resulting bad contact between the brushes and commutator. This frequently results in the insulation between the segments being so badly charred that "flashing over" takes place, this practically amounting to a dead short circuit between the brush-holders of opposite polarity, resulting, perhaps, in the burning out of the armature and destruction of the brushes and brush-holders. When metallic brushes are employed it is advisable to use mineral oil, such as vaseline or any other hydrocarbon; animal or vegetable oils should be avoided as they are more likely to carbonise. Oil is not to be recommended for carbon brushes; excellent results can be obtained with these brushes by soaking them in hot liquid vaseline or paraffin wax. If considered more convenient, the paraffin wax may be used in the form of sticks or blocks. A stick rubbed lightly on the commutator occasionally will keep it in excellent condition.

Trimming Brushes.—At certain intervals, according to the care taken to reduce sparking, and the length of time the machine runs, the brushes will fray out or wear unevenly, and will therefore need trimming. They should then be removed from the brush-holders, and their contact ends or faces examined. If not truly square, they should be filed or clipped.

with a pair of shears, the course of treatment differing with the type of brush. If metal strip brushes, the feathered-out ends should be clipped square with a pair of shears, the ends thoroughly cleaned from any dirt or carbonised oil, and replaced in their holders. Gauze and wire brushes require a little more attention. When their position on the commutator has been well adjusted and looked after, so that little or no sparking has taken place, it will generally be only found necessary to wipe them clean, and clip off the fringed edges and corners with the shears, or a pair of strong scissors. If, however, the machine has been sparking, the faces will be worn or burnt away, and probably fused. If such is the case, they will need to be put in the filing clamp and filed up square and true, as directed above. If the contact faces of the brushes are very dirty and covered with a coating of carbonised oil, &c., it will be necessary to clean them with benzoline or soda solution before replacing. The handiest way of trimming carbon brushes, or of bedding a complete new set of metal brushes, is to bind a piece of fine glass or sand paper, face outwards, around the commutator after the current has been shut off, and grind them down in the manner described on page 173. If it becomes necessary, through sparking or other causes, to trim the brushes while the machine is working, one brush at a time should be removed from the holders. The brush to be removed should first be raised carefully from the commutator; then, if excessive sparking or heating occurs, the brush should be let down again, and the tension of the springs of the brushes temporarily increased until the

brushes are trimmed. This of course only applies to machines provided with at least two brushes to each set. If only one brush is provided, the machine must be stopped before the brushes can be trimmed.

Shutting down Dynamo.—When shutting down a machine, the load should first be gradually reduced, if possible, by easing down the engine; then, when the machine is supplying little or no current, the main switch should be opened. This reduces the sparking at the switch contacts, and prevents the engine racing. When the voltmeter almost indicates zero, the brushes, if metallic, should be raised from contact with the commutator. This prevents the brushes being damaged in the event of the engine making a backward motion, which it often does, particularly when it is a gas-engine. On no account, however, should the brushes be raised from the commutator while the machine is generating any considerable voltage; for not only is the insulation of the machine liable to be damaged by this proceeding, but in the case of large shunt dynamos an exceedingly violent shock is liable to be administered to the person lifting the brushes. When carbon brushes are used, placed butt-end on the commutator, it is of course not necessary to raise them from the commutator when stopping. When the dynamo is at rest, or only revolving slowly, and the brushes are raised from the commutator, the latter should be cleaned up, if this is necessary. In dusty places, such as flour mills, sugar works, cement works, &c., it will probably be necessary to clean off the commutator with benzoline, and finally with finest glass cloth, at the end of every run. In places free from dust, it

will only be necessary to wipe the revolving surface perfectly clean, or until it will not soil a white rag, and occasionally to apply a little fine glass paper before stopping. When the machine is stopped it should be thoroughly cleaned up. The armature should be dusted with a pretty stiff brush from any adherent copper dust, dirt, &c., and the other portions of the machine should be thoroughly cleaned with linen rags. Waste should not be used, as it is liable to leave threads, fluff, &c., on the projecting parts, terminals, and other parts of the machine, and on the windings of the armature, which is very difficult to remove. If the machine be installed in a work-shop where iron filings exist, it should be examined now and then to see that none have been attracted by the magnets, either outside or inside the armature chamber; if so, they should be at once cleaned off. The brushes should be examined, and if necessary trimmed and adjusted, and all terminals, screws, bolts, &c., carefully cleaned and screwed up ready for the next run. The brush-holders should receive special attention, as when dirty they are liable to stick and cause sparking. All dirt and oil should be removed from the springs and contacts, and pivots and other working parts. It is advisable at stated intervals to entirely remove the brush-holders from the rocker arms, and give them a thorough clean up, by taking them to pieces, and cleaning each part separately with emery cloth and benzoline or soda solution. Another point to which particular attention should be given is the cleaning of the brush rocker. This being composed wholly of

metal, and the two sets of positive and negative brushes being only separated from it by a few thin insulating washers, it follows that if any copper dust given off by the brushes is deposited in the neighbourhood of these washers, there is considerable liability for a dead short circuit of the machine to occur, by the dust bridging across the insulation. These particular parts should therefore be kept scrupulously clean, and free from any conducting matter.

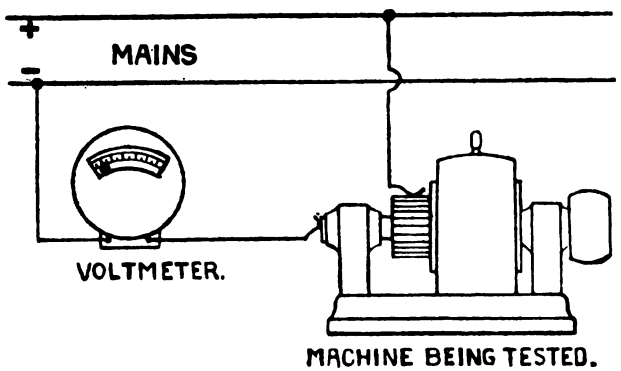


FIG. 90.

Testing Insulation Resistance.—It is a good plan, when the machine has been thoroughly cleaned up and all connections made secure, to occasionally test the insulation of the different parts and also that of the windings of the entire machine from earth with an ohmmeter or Wheatstone Bridge. If a record is kept of these tests, any deterioration of the insulation of the machine can at once be detected, localised, and remedied before it has got far enough to cause a

breakdown. In testing the insulation resistance of a dynamo, the rule is to allow the insulation resistance of the dynamo to be such that at the rated voltage of the machine not more than $\frac{1}{1000000}$ of the full load current will be sent through the insulation. When the value thus found exceeds one megohm, one megohm may be considered as sufficient. If an ohmmeter or Wheatstone Bridge is not available, a convenient method of testing the insulation resistance of a dynamo is by means of the "voltmeter test." To enable this test to be carried out it is necessary to have a sensitive high resistance voltmeter of which the exact resistance is known. In most high-class instruments this is usually marked on the case. Assuming the instrument to have a resistance of 25,000 ohms and to be capable of reading to 250 volts, it is connected to a live circuit having as high a voltage as possible, but not exceeding the voltage the voltmeter is capable of reading, say 200 volts, and the exact voltage of the circuit is measured. It is then connected to the dynamo as shown in Fig. 90, one terminal being connected to the frame of the dynamo and the other terminal to one or other of the mains. The insulated windings of the dynamo are then connected to the other main, and the deflection or reading noted on the voltmeter. This will be found to be less than before in proportion to the value of the insulation resistance. The insulation resistance of the dynamo is then found by equation—

$$\text{Insulation Resistance} = \frac{D \times R}{d} - R,$$

in which D is first and d second deflection, and R is resistance of voltmeter. Assuming the voltage of the

circuit to be 200 volts, and the second deflection through the insulation resistance of the dynamo to be 2 volts, then

$$\text{Insulation Resistance} = \frac{200 \times 25{,}000}{2} - 25{,}000 = 2{,}475{,}000 \text{ ohms.}$$

As a means of protecting the machine from any moisture, dirt, &c., while standing idle, it is advisable to cover it up with a suitable waterproof cover.

CHAPTER XI.

FAULTS IN DYNAMOS.

THE principles governing the electrical and mechanical design and construction of dynamos and motors are now so well understood, that no excuse can now be advanced in extenuation of defects due to these causes. At the same time, it may be pointed out that even in electrical machinery of the best class faults are liable to develop at some period or other, either through accident, neglect, or improper treatment, or even fair wear and tear, which may have the effect of either partially or wholly preventing the machine carrying out its proper functions.

In the early days of the electrical industry, when the scientific principles of design and construction were by no means fully understood, even by those who made a speciality of the subject, and when the mechanical forces at work in a running dynamo or motor were not so fully realised as they are at the present time, machines were as a rule constructed upon some *rule of thumb* method discovered by the particular maker. As a consequence it was no uncommon occurrence for the segments of the commutator to fly out at some time or other when the machine was working; in other cases, armatures of the ring type,

previous to the introduction of metal spiders, were constructed with their cores and windings driven over a wooden hub fixed to the shaft. In course of time the heat generated by the armature caused the wood to shrink, with the result that the core parted company with the hub. Even after the application of the metal clamping spider to armature cores, the core discs were frequently so loosely clamped or bound together that in course of time, they were liable to work loose amongst themselves and eventually cut through the insulation of the windings, thus short-circuiting the armature. The comparatively enormous forces brought into play amongst the armature conductors, when the machine was subjected to an overload, was also a frequent source of trouble. As a general thing the armature cores of such machines were unprovided with drivers, and slotted cores were rarely used, the result being that when the overload was suddenly applied, which in most cases always happens, the conductors remained stationary for a brief interval while the core continued to revolve—this resulting, if the coils were at all loosely wound, in the conductors being dragged out of their places over the core, and either the binding bands burst or the ends of the coils torn from the commutator segments. Even up to a comparatively recent period, the armature shaft or spindle was rarely constructed with sufficient thickness or strength to ensure stiffness under working conditions, and the feathers used for securing the armature cores to the shaft also frequently gave trouble and caused break-downs, through insufficient depth being provided to secure the rigid connection of the core to the shaft. These defects, with others of a similar nature, have

now, however, been so well recognised and eliminated that a modern dynamo rarely gives any trouble, and is capable of running for long periods at a time, with a minimum of attention. In the following paragraphs, faults liable to occur, under ordinary circumstances, to the latter class of machine only are considered, to the exclusion of those due to bad design and construction; if a machine, possessing the characteristics and disabilities mentioned above, commences to give trouble, the best policy is to get rid of it, otherwise, it will be a constant source of expense and annoyance.

Testing Battery and Galvanometer.—As in the detection of electrical faults in dynamos a testing battery and galvanometer are indispensable, a few words regarding the construction and use of the most suitable types may not be out of place. In regard to the battery, a few cells of any of the well-known types as used in bell and telephone work, such as the Leclanche, Dry, Daniell, &c., are suitable. In reference to the galvanometer, a lineman's detector, or any ordinary sensitive galvanometer, will answer the purpose. A form of testing battery and galvanometer, specially designed and constructed for this class of work, is illustrated in Fig. 91. The battery consists of a number of small Leclanche cells, each contained in a sealed ebonite case. The cells are connected in series, and contained in a hardwood outer case, which also contains the galvanometer when not in use. The positive and negative poles of the battery are connected to two brass terminals fixed upon the outside of the case, by means of which the battery may be

connected to the galvanometer or the appliance, or circuit under test. The galvanometer consists of a pair of astatic magnetic needles, suitably arranged between a pair of bobbins or coils wound with fine insulated wire. The ends of the coils or bobbins are connected to two brass terminals, which are fixed upon two ebonite insulating blocks projecting through the brass case. When an electric current

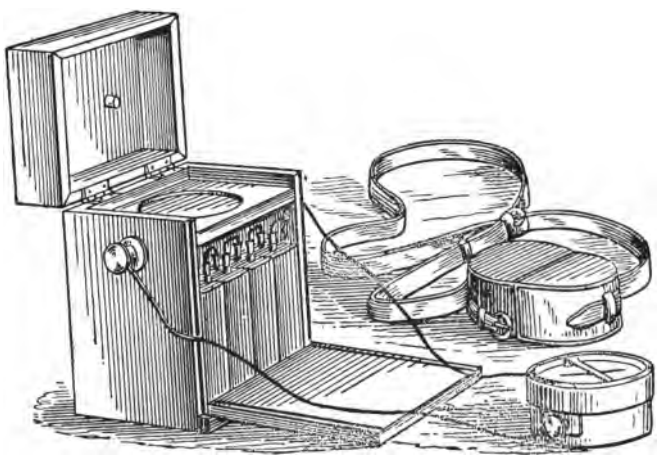


FIG. 91.

flows through the wire coils a magnetic field is created, and the needles are deflected to a greater or lesser degree in accordance with the strength of the current flowing in the coils. In testing for faults, two methods of connecting up the battery and galvanometer to the circuit under test are employed, these being termed the *conductivity* test and the *insulation* test respectively.

Testing for Conductivity.—In making this test, the instruments are connected as represented in Fig. 92. B is the battery, G the galvanometer, and S is a coil of wire being tested for electrical continuity or conductivity. As will be seen, the positive pole + of the battery is connected to one terminal of the galvanometer, and the other or negative pole is connected to one of the ends of the coil under test. The

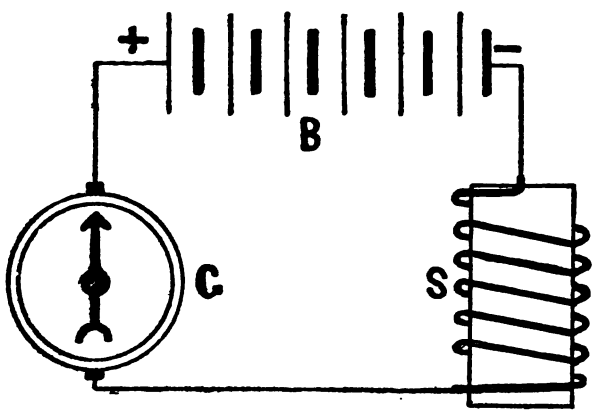


FIG. 92.

other terminal of the galvanometer is connected to the other end of the coil. If the connecting wires are making good electrical contact with the respective terminals, and the wire of the coil being tested is unbroken, the needle of the galvanometer will be deflected as soon as a closed circuit is made by the end of the coil coming into contact with the galvanometer terminal. If the wire of the coil is broken in

some part, or the ends of the connecting wires do not make good electrical contact with the terminals, the needle will not be deflected. In order to prevent mistakes, it is advisable to test the battery and galvanometer connections and contacts by short circuiting or bringing the ends of the wires connecting the terminal of the galvanometer and negative pole of the battery together, before starting to

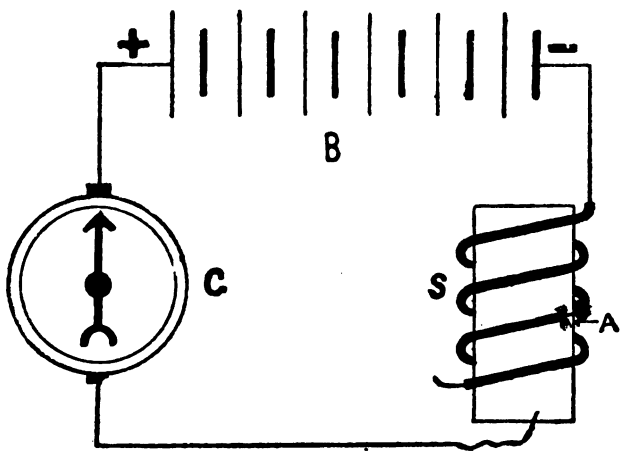


FIG. 93.

test the circuit or coil. If the needle is deflected, the connections are all right; if undeflected, there is a bad contact somewhere which must be made good before the test can proceed.

Testing for Insulation.—The object of this test is to ascertain whether the insulation of a circuit or of the wire wound upon a metal spool or core, such as a magnet core, has broken down or is in good order.

In making the test, the instruments and connections are arranged as shown in Fig. 93. The battery and galvanometer are connected to one another, as in the conductivity test described above. The unconnected terminal of the battery is connected to one end of the coil under test, the other end of the coil remaining free and unconnected. Some portion of the metal core, say the end, is then cleaned bright with a knife or emery cloth, and the unconnected terminal of the galvanometer is brought into contact with this bright or clean part of the core. If then some portion of the insulation of the wire has been abraded or destroyed, thus bringing the bare wire into contact with the metal core, as at A in the figure, the needle of the galvanometer will be deflected, since a closed circuit is formed through the core and wire. If, on the contrary, the insulation is perfect, the needle will be undeflected. It will thus be seen that in the conductivity test it is needful that the needle should be deflected to prove that all is right, whilst in the insulation test the converse holds good. If the needle is deflected, it proves that the insulation has broken down.*

Faults in Dynamos.—The chiefest irregularities

* It may here be mentioned that a test made while the machine is not running, and which may give satisfactory results, is not necessarily a conclusive proof that the windings of the machine are in perfect condition. One of the most difficult faults to discover is a short circuit or ground in the armature, which only takes place when the armature is revolving, and which is generally due to two adjacent or consecutive armature windings being either forced together or brought into electrical connection with the binding wire or core of the armature, through the agency of centrifugal force or magnetic attraction, just at a point where the insulation happens to be in bad condition, or where the insulation has been damaged

to which a dynamo is subject may be enumerated as follows :—

A. *Failure to excite.*
B. *Sparking at brushes.*
C. *Excessive heating.*
D. *Excessive noise or vibration.*
E. *Variation or decrease of speed.*
F. *Variation of voltage.*

Each of these irregularities may be due to a number of causes, acting either singly or in combination. A list of the defects or faults tending to produce a given irregularity is given under each heading when the same is under consideration in the succeeding paragraphs, and it will be necessary to test for each in turn until the true defect or fault producing the abnormal performance is located.

A. **Failure to Excite.**—This is of frequent occurrence in both old and new machines, and is generally due to one or other of the undermentioned causes. It may be pointed out, *en passant*, that compound and shunt wound machines require an appreciable amount of time, in some cases, five minutes may elapse before they fully excite. With such machines, it is therefore best not to be too hasty in hunting for faults if the voltage is not immediately produced on starting the machine.

(1.) Brushes out of neutral points.
(2.) Defective contacts.
(3.) Field regulator incorrectly adjusted.
(4.) Incorrect connections.
(5.) Insufficient speed.
(6.) Open circuits.
(7.) Short circuits or over loads in external circuit.
(8.) Insufficient residual magnetism.
(9.) Reversed magnetism in fields.
(10.) Field coils acting in opposition.
(11.) Short circuits in dynamo.

through some defect existing in the binding wires or core. Consequently it may be considered advisable to test, while the machine is running, in all cases where it is suspected that some obscure fault exists in the armature, which it is difficult to localise.

A (1.) *Brushes out of Neutral Points.*—The first point to be observed, if the machine fails to excite, is the position of the brushes upon the commutator. If these are not on or near the neutral points, the whole of the E. M. F. of the armature will not be utilised, and will probably be insufficient to excite the machine. The correct positions for the brushes have already been described in Chapter X. (Running Dynamos). If in doubt as to the correct positions, the brushes should be rotated by means of the rocker into various points on the commutator, sufficient time, say five minutes, being given the machine to excite before moving them into a new position.

A (2.) *Defective Contacts.*—If the different points of contact of the connections of the machine are not kept thoroughly clean and free from oil, &c., it is probable that such resistance will be interposed in the path of the exciting current as to prevent the machine building or exciting. It may be remarked that the battery and galvanometer is not a decisive test for this fault, as the needle may be deflected through a resistance, due to a bad contact, much too great to allow of the small E. M. F., generated on first starting the machine, to send a current sufficiently great to build the machine. Each of the contacts should therefore be examined, and cleaned, and screwed up tight. The chief point to which attention should be given is the contact faces of the brushes and surface of the commutator. In badly attended and neglected machines these are very frequently covered with a slimy coating of oil and dirt, which is quite sufficient to prevent the machine exciting. In this case the brushes and

commutator should be cleaned up as directed in Chapter X. (Running Dynamos).

A (3.) *Field Regulator incorrectly adjusted.*—Shunt and compound wound machines are very frequently provided with field regulators for inserting or removing resistance into the field circuit. When such is the case, it is possible the resistance in circuit may be too great to allow of the necessary strength of exciting current passing through the field windings. Therefore, in all cases before starting, remove by cutting out or short circuiting the whole of the resistance coils from circuit. The field coils of series machines are sometimes provided with short circuiting switches or resistances arranged to shunt the current across the field coils. In this case there may not be sufficient resistance in circuit, and therefore almost the whole of the exciting current will be shunted across in place of passing through the field coils. The remedy in this case is to open the switch completely, or, if this cannot be effected, to cut in sufficient resistance to enable sufficient current to pass through the field windings to excite the machine.

A (4.) *Incorrect Connections.*—When the machine is first erected, the failure to build may proceed from incorrect connections. The whole of these latter should therefore be traced or followed out, and compared with the diagrams of field and dynamo connections given in Figs. 51 to 68.

A (5.) *Insufficient Speed.*—In shunt and compound dynamos there is a certain *critical* speed below which they will not excite. If the normal speed of the machine is known it can at once be seen whether the

failure to build arises from this cause, by measuring the speed of the armature with a speed indicator. In all cases it is advisable, if the machine does not excite in the course of a few minutes, to increase the speed to a certain extent. As soon as the voltage rises, the speed may be reduced to its normal value.

A (6.) *Open Circuits.*—The manner in which the different types of machines are affected by *open circuits* is dependent upon the class of machine. In the shunt machine it is necessary to have the external circuit open before it will build, whilst in the series machine it is needful to have it closed under like circumstances. Open circuits are most likely to occur in (*a*) Armature circuit; (*b*) Field circuit; (*c*) External circuit.

(*a*) *Open Circuit in Armature.*—The localisation and repair of faults in this circuit are described in Chapter XII. (Faults in Armatures). When the open circuit is due to the brushes not making good contact with the commutator, simple examination generally reveals the defect, which may be remedied as directed in A (2) (Defective Contacts).

(*b*) *Open Circuit in Field Circuit.*—This may be caused by bad contacts at the terminals, or broken connections, or fracture of the coil windings. In such cases remove the flexible leads attached to the brushes from their connection with the field circuit, and test for conductivity with a galvanometer, the fault may then be readily localised. If the machine is shunt wound, it may occur in the hand regulator through a broken resistance coil or bad contact. Very frequently the fault occurs in the connecting wires leading from the machine to the hand regulator

fixed upon the switchboard, or in the short wires connecting the field coils to the terminals or brushes. The insulation of a wire will sometimes hold the two ends of a broken wire together so as to defy any but the most careful inspection or examination; therefore, in order to avoid loss of time, it is advisable to disconnect the wires if possible, and test each separately for conductivity with a battery and galvanometer connected, as in Fig. 92. If the fault is not located in the various connections, the magnet coils should be tested with the battery and galvanometer coupled up as in Fig. 92, care being first taken to disconnect the ends of each of the coils. A faulty coil will not show any deflection of the galvanometer. Having located the faulty coil, the discontinuity or break should be searched for and rectified. In the shunt coils of shunt and compound dynamos, and these are most liable to this defect, the break invariably occurs at the point where the wire passes through the flanges of the spool or bobbin. In most cases a little of the wood or metal of which the flange is made can be gouged or chipped out, and a new connecting wire soldered on to the broken end of the coil without much difficulty. If it is necessary to take the magnets apart at any time, great care should be taken in putting them together again to wipe all faces perfectly clean, and screw up firmly into contact, the connections of the coils being made as before taken apart. If the faulty coil cannot be repaired quickly, and the machine is urgently required, the coil may be cut out of circuit entirely, or short circuited, and the remaining coils coupled up so as to produce the correct polarity in the pole pieces.

In this case, however, as the coils are liable to heat up to a greater extent than formerly, owing to the increased current, it is advisable to proceed cautiously in starting the dynamo, in case the temperature exceeds a safe limit. If this occurs, a resistance may be put in circuit with the field coils, or the speed of the dynamo reduced.

(*c*) *Open Circuit in External Circuit.*—Series wound machines are only affected by this occurrence. If the disconnection is complete, the fault may readily be located by the battery and galvanometer coupled up as in Fig. 78. If only partial, however, this fault is very elusive, for the reasons mentioned in A (2) (Defective Contacts). If the external circuit tests out apparently all right, and no defective contacts are apparent in any part of the machine, and all short circuiting switches, &c., are cut out of circuit, and the machine still refuses to excite, short circuiting the terminals of the machine should be tried. This should be effected very cautiously, especially if a high tension machine. It is advisable to have, if possible, only a portion of the load in circuit, and the short circuit should be effected as shown in Fig. 94 AB. The short circuit may be made by momentarily bridging across the two terminals of the machine with a single piece of wire. As this, however, is liable to burn the terminals, a better plan is to fix a short piece of scrap wire in one terminal, and then with another piece of insulated wire make momentary contacts with the other terminal and the short piece of wire. If the machine excites, it will be at once evident by the arc which occurs between the two pieces of wire. As the voltage of a series machine

when induced to build in this manner generally rises very rapidly, great care should be taken that the contact is at first only momentary, merely a rubbing or scraping touch of the wires. The contact may be prolonged if the machine does not excite at the first contact. Compound wound machines can often be

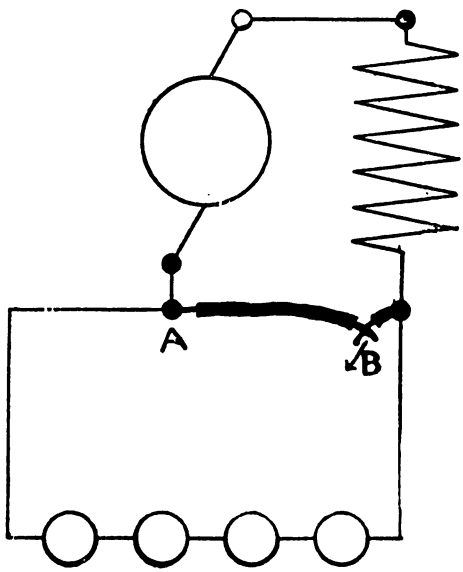


FIG. 94.

made to excite quickly by short circuiting their terminals in this manner.

A (7.) *Short Circuits or Excessive Load in External Circuit.*—A shunt machine will not excite under these circumstances, for the reason that practically the whole of the current generated in the armature passes direct to the external circuit, and the differ-

ence of potential between the shunt terminals is practically nil. If it is suspected that the failure to excite arises from this cause, the main leads should be taken out of the dynamo terminals, when, if due to this cause, the machine will excite. When the machine is compound or series wound, a fault of this description causes the machine to overload and blow the fuses. If due to overload, this latter should be removed as directed in B (4) (Overload of Dynamo).

A (8.) *Insufficient Residual Magnetism.*—This fault is not of frequent occurrence, and it is almost impossible for it to take place if the field magnets are of cast-iron. It always occurs when the dynamo is a new one, or when the field magnets have been taken apart for repairs, &c. It may be remedied by passing the current from a few storage cells, or another dynamo, for some time in the proper direction through the field coils. If a heavy current, such as is obtainable from a storage battery, is not available, and the machine is shunt or compound wound, a few Leclanché or dry cells, arranged as in Fig. 95, will generally effect the purpose. The flexible "lead" (L) of the dynamo (D) is disconnected from the positive terminal of the machine, and is connected to the negative or zinc pole of the battery (B), the other or positive carbon pole being connected to the terminal, from which the lead was removed, and shunt circuit (S). As thus arranged, it will be seen that the battery (B) is in series with the armature and shunt circuit, and therefore its E. M. F. will be added to any small E. M. F. generated in the armature. When the machine is started, the combined E. M. F.s will probably be able to send sufficient current through

the shunt to excite the machine. As the voltage rises and the strength of the current in the shunt windings increases, the flexible lead may be again inserted into the terminal from which it was removed.

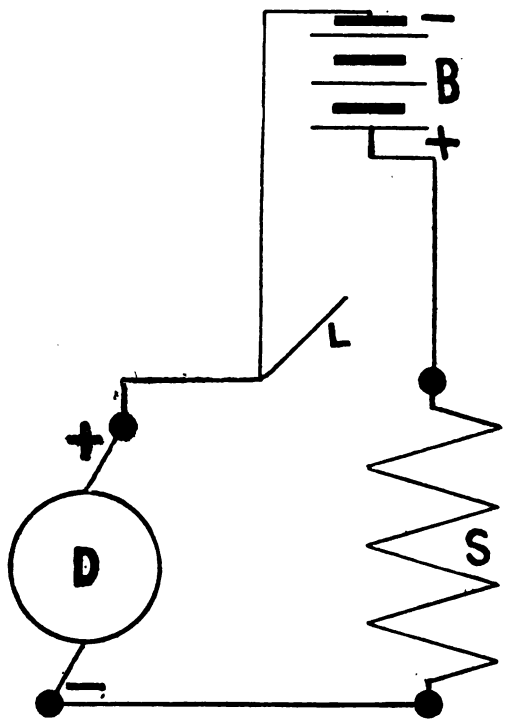


FIG. 95.

The battery will thus be short circuited, and may be cut out of circuit without any danger of breaking the shunt circuit, and thus causing the machine to demagnetise.

A (9.) *Reversed Magnetism in Fields.*—This also is a fault of infrequent occurrence. It may be caused by the proximity of other dynamos, but is generally due to reversed connections of the field coils. Under such conditions the field coils tend to produce a polarity opposed to the magnetisation to which they owe their current, and therefore the machine will refuse to excite until the field connections are reversed, or a current is sent from another dynamo or a battery through the field coils in a direction to produce the correct polarity in the pole pieces.

A (10.) *Field Coils acting in Opposition.*—This may occur when the dynamo is a new one, or the coils have been removed for repairs. It may be caused either through the coils having been put on the field cores the wrong way, or through incorrect coupling up. Under these circumstances, the dynamo, if bi-polar, will fail to excite; and if multipolar, poles will be produced in the yokes, &c. It may be remedied by removing one of the coils from the core and putting it on the reverse way, or by reversing its connections. The connections of all the coils should be verified by applying Professor Jamieson's rule given on page 21. The manner of coupling up the coils of the different types of field magnets will be understood by reference to Figs. 60 to 68. In compound dynamos it sometimes happens that the machine will excite properly, but that the series coils tend to reverse the polarity of the dynamo, thus reducing the voltage as the load upon the machine increases. This may be detected when the machine is loaded by short circuiting the *series coils, not* the *terminals.* If the voltage rises in doing this, the series coils are

acting in opposition to the shunt coils, and the connections of the *series coils* must be reversed.

A (11.) *Short Circuits in Dynamo.*—A dynamo may refuse to excite through some portion of its windings or connections being short circuited, for the reason that the field magnets are deprived of the necessary current required for building the machine. Short circuits most frequently occur in (*a*) Terminals; (*b*) Brush-holders; (*c*) Commutator; (*d*) Armature coils; (*e*) Field coils.

(*a*) *Short Circuits in Terminals.*—The terminals of the various circuits of the machine are liable to be short circuited, either through metallic dust bridging across the insulation, or through the terminals making direct contact with the frame of the machine. The various terminals should be examined, and if the fault cannot be located by inspection, they should each be disconnected from their circuits and tested with a battery and galvanometer arranged as in Fig. 82. B is the battery, one pole of which is placed in contact with the frame of the machine at a point which has previously been well scraped and cleaned; the other pole is connected to one of the galvanometer terminals as shown. The other terminal of the galvanometer is connected to each of the dynamo terminals (T T) under test in turn. If a deflection of the needle is produced when the galvanometer terminal is in contact with either, the terminals are in contact with the frame, and they should then be removed, and the fault repaired by additional insulation or by re-insulating.

(*b*) *Short Circuits in Brush-holders.*—As previously mentioned, the brush-holders are liable to be short

circuited through the rocker by metallic dust lodging in the insulating washers. These points should therefore be examined and cleaned, and the two sets of brush-holders tested for short circuits between them. To test the brush-holders, the brushes should be

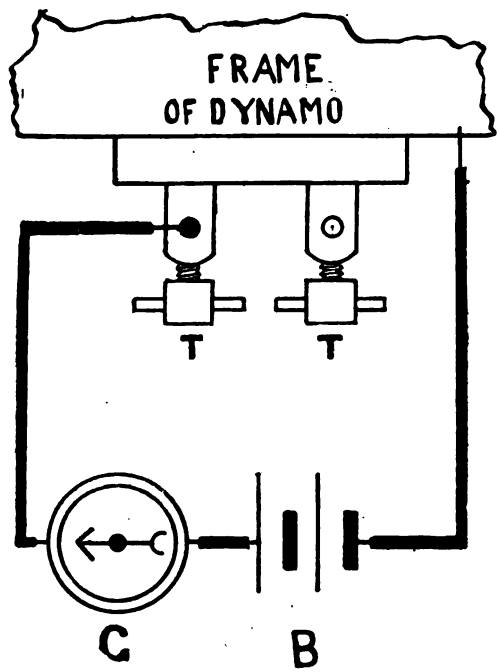


FIG. 96.

raised from contact with the commutator by means of the hold-off catches, and all connecting cables removed. The galvanometer and battery should then be coupled up, as in Fig. 93, and one terminal of the galvanometer connected to one set of brushes,

and the other set placed in connection with the unconnected terminal of the battery. If the needle is deflected when thus connected, the brush-holders are short circuited through some point, when they should be taken out of the rockers and the fault repaired.

(*c*) *Short Circuits in Commutator;* (*d*) *Short Circuits in Armature Coils.*—The localisation and repair of faults in these parts of a dynamo are fully described in Chapter XII. (Faults in Armatures).

(*e*) *Short Circuits in Field Coils.* — When short circuits occur in the field coils or circuit, the machine as a rule refuses to excite. The short circuit may be in the terminals or connections, and these should first be examined and tested as described above (*a*). When in the field coils, the fault may be detected by measuring the resistance of each of the coils with an Ohmeter or Wheatstone Bridge. The faulty coils will show a much less resistance than the perfect coils. The fault may also be discovered and located by passing a strong current from a battery or another dynamo through each of the coils in turn, and observing the relative magnetic effects produced by each upon a bar of iron held in their vicinity. Some series dynamos are provided with a resistance, arranged in parallel or shunt with the field coils, to divert a portion of the current therefrom, and thus regulate the output. When making a series dynamo excite, all resistances and controlling devices should be temporarily cut out of circuit by opening the shunt circuit. Series machines have frequently a switch which short circuits the field coils. Care should be taken that this is open, or otherwise the machine will not excite.

B. **Sparking at Brushes.**—In all good dynamos there are certain positions upon the commutator for the brushes at which there will be absolutely no sparking so long as the commutator is kept clean and in good condition. In other dynamos, badly designed or constructed, sparking occurs at all positions, no matter where the brushes are placed, and in such dynamos it is therefore impossible to prevent sparking at the brushes, no matter how well they are adjusted. When sparking occurs at the brushes of a good dynamo, two kinds may generally be distinguished by the practised eye, viz., those sparks due to bad adjustment of the brushes, generally of a bluish colour, small when near the neutral points, and increasing in violence and brilliancy as the brushes recede from the correct positions upon the commutator; and those due to dirty and neglected state of the commutator and brushes, these being distinguished by a reddish colour and a spluttering or hissing. When due to this last-mentioned cause, it is impossible to suppress the sparking until the commutator and brushes have been cleaned up. In the former case, the sparks will disappear as soon as the brushes have been rotated into the neutral points. Another class of sparks appear when there is some more or less developed fault, such as a short circuit, or disconnection in the armature or commutator. These are similar in character to those produced by bad adjustment of the brushes, but are distinguished from the latter by their not decreasing in violence as the brushes are rotated towards the neutral points. Having distinguished the classes of sparks which appear at the commutator of a dynamo, it remains

to enumerate the causes tending to produce sparking. These are :—

(1.) Bad adjustment of brushes.
(2.) Bad condition of brushes.
(3.) Bad condition of commutator.
(4.) Overload of dynamo.
(5.) Loose connections, terminals, &c.
(6.) Disconnections in armature circuit.
(7.) Short circuits in armature circuit.
(8.) Short circuits or disconnections in field magnet circuit.

B (1.) *Bad Adjustment of Brushes.*—When sparking is produced by bad adjustment of the brushes, it may be detected by rotating or shifting the rocker, by the indication that the sparking will vary with each movement. To obtain good adjustment of the brushes, it will be necessary to rock them gently backwards and forwards, as directed in Chapter X., until a position is found in which the sparking disappears. If a position cannot be found at which the sparking disappears, it is probable that the brushes are not placed diametrically apart upon the commutator, or that the neutral points are not situated in their true theoretical positions upon the commutator through some defect in the winding, &c. In this last-mentioned case, the brushes may be strictly adjusted to their theoretically correct positions before starting the machine; then, when the machine is started and the load put on, violent sparking occurs, which cannot be suppressed by shifting the rocker. If, however, one set of brushes only is observed, it will generally be found that, at a certain position, the sparking at the set

of brushes under observation ceases or is greatly reduced, while sparking still occurs at the other set. When this position is found, the rocker should be fixed by the clamping screw, and the brushes of the other set at which sparking is still occurring adjusted by drawing them back or pushing them forward in their holders until a position is found at which the sparking ceases, at which they should be fixed. Correct position of the brushes upon the commutator and the suppression of sparking is a matter of great importance, and any time spent in carefully adjusting will be amply repaid by the decreased attention and wear of the brushes and commutator.

B (2.) *Bad Condition of Brushes.*—If the contact faces of the brushes are fused or covered with carbonised oil, dirt, &c., there will be bad contact between the brushes and commutator, and consequently great heating and sparking. Simple examination will generally reveal whether this is the case. The remedy is to remove the brushes, one at a time if the machine is running, clean, file if necessary, trim, and readjust. If the brushes are exceedingly dirty, or saturated with oil, it will be necessary to clean them with turpentine, benzoline, or soda solution, before replacing.

B (3.) *Bad Condition of Commutator.*—If the surface of the commutator is rough, worn into grooves, or excentric, or has one or more segments loose, or set irregularly, the brushes will be thrown into vibration, and sparking will result, especially if carbon brushes are in use. A simple examination of the commutator will readily detect these defects. If the commu-

tator is untrue, the fact will be indicated when the machine is slowed down by a visible eccentricity, or by holding the hand, or a stick in the case of high tension machines, against the surface while revolving, when any irregularity or eccentricity will be apparent by the vibration or movement of the stick. The only remedy for an eccentric commutator is to re-turn it as directed in Chapter X. (Running Dynamos, &c.). Loose or high or low segments may be detected by the same means. The remedy for high segments is to tap them gently down with a small hammer or mallet, and if possible tighten up the clamping cones at the ends of the commutator. If it is impossible to hammer the segments down, they should be filed down level with the rest of the commutator, or the commutator re-turned. For low segments, the only remedy is to pull out the segments as directed in Chapter XII. (Faults in Armatures), or turn commutator down to their level.

Sometimes, when an excess of oil has been used as lubricant, or oil has been allowed to overflow on to the commutator from the bearings, it gives rise to excessive sparking. The carbonised oil forms a conducting medium between commutator bars which can readily be seen by a number of sparks passing between bars. Finally, this conducting medium will form a short circuit from positive to negative brush, or, in other words, the current will "flash over," and probably result in the brushes and brush-holders being fused, and the armature burnt out. If the excess of oil arises from defective bearings, measures should be taken to render them efficient without

delay, by providing suitable "oil flingers" on the shaft. A short circuit between two bars of a commutator also tends to cause sparking, and will be easily recognised by the blackening of the bars, and also by the abnormal heating of the coils connected thereto. Sometimes it may be caused by a piece of metal getting between the bars or by a loose piece of solder dropped in between the commutator lugs or leads. More often it is due to sparking from some cause burning the mica. The spaces then get filled with carbon and copper dust, thus forming a permanent short circuit. The remedy is to clear away all dirt and scrape clean, and fill up with a mixture composed of litharge mixed with glycerine, to the consistency of a thick paste, and afterwards baked into the commutator. Often considerable damage is done to a commutator through the mica insulation not wearing evenly with the copper; in this case the mica should preferably be reduced by stoning, and then grooved out to a V shape between the bars.

B (4.) *Overload of Dynamo.*—It may happen through some cause or other that a greater output is taken from the machine than it can safely carry. When this is the case, the fact is indicated by excessive sparking at the brushes, great heating of the armature and other parts of the dynamo, and possibly by the slipping of the belt (if a belt-driven machine), resulting in a noise. The causes most likely to produce overload are:—(*a*) Excessive voltage; (*b*) Excessive current; (*c*) Reversal of polarity of dynamo; (*d*) Short circuits or grounds in dynamo, or external circuits.

(*a*) *Excessive Voltage.*—This will be indicated by the voltmeter, and by the brightness of the pilot lamp. It may be caused either by excessive excitation of the field magnets, or by excessive speed. In the former case, resistance should be introduced into the field circuit to diminish the current flowing therein if a shunt machine; or if a series machine, a portion of the current should be shunted across the field coils by means of a resistance arranged in parallel with the series coils; or the same effect may be produced in both cases by reducing the speed of the armature if this is possible. If due to excessive speed, which will be indicated by a speed indicator, the natural remedy is to reduce the speed of the motor driving the dynamo, or, if this is not possible, insert resistance into the dynamo circuit, as described above.

(*b*) *Excessive Current.*—This will be indicated by the ammeter. If the dynamo is supplying arc lamps, the excessive current may possibly be caused by the bad feeding of the lamps. If this is the case, the fact will be indicated by the oscillations of the ammeter needle, and by the unsteadiness of the light. If incandescent lamps are in circuit, the fault may be caused by there being more lamps in circuit than the dynamo is designed to carry. Under such circumstances, another dynamo should be switched into circuit in parallel, or, if this is not possible, lamps should be switched off until the overload is reduced. When electro-motors are in circuit, sparking frequently results at the dynamo commutator, owing to the fluctuating load. In such cases the brushes should be adjusted to a position at which the least sparking occurs with the average load.

(*c*) *Reversal of Polarity of Dynamo.*—When compound or series wound dynamos are running in parallel, their polarity is occasionally reversed while stopping by the current from the machines at work. Under such conditions, when the machine is again started, the E. M. F. of one is added to that of another, or the machines are connected in series, so that a closed circuit is formed, and as a consequence an enormous current results. Before the machine can be again coupled in parallel, it will be necessary to send a current through the field coils in the reverse direction.

(*d*) *Short Circuits or Grounds in Dynamo or External Circuits.*—A dynamo is liable to be overloaded through bad insulation of the dynamo or external circuits, resulting in a considerable leakage of current, in which case the ammeter will probably not indicate the fact. To ascertain if this is the case, connect a piece of insulated wire to one of the terminals of the machine while running, and then make short momentary contacts with the ground through a water pipe, or frame of the dynamo, or other body in good connection with the earth. If a flash occurs, it proves that the insulation is defective somewhere. This test should be applied to each of the terminals in turn. The fault should next be located by taking the mains to the external circuit out of the terminals of the machine, and again testing as before. If a flash again occurs, it proves that the defect exists in the dynamo, which should be stopped, and the terminals, &c., tested with a battery and galvanometer, as directed in A (11) (Short Circuits in Dynamo). It must be clearly understood that a fault of this description is

just as likely to occur in the external circuit, and therefore, if after removing the mains from the terminals of the machine, and again testing, the flash disappears, it may be taken that the fault is in the external circuit, which should be tested in a similar manner to the dynamo.

B (5.) *Loose Connections, Terminals, &c.*—When any of the connecting cables, terminal screws, &c., securing the different circuits are loose, sparking at the brushes, as a rule, results, for the reason that the vibration of the machine tends to continually alter the resistance of the various circuits to which they are connected. When the connections are excessively loose, sparking also results at their points of contact, and by this indication the faulty connections may be readily detected. When this sparking at the contacts is absent, the whole of the connections should be carefully examined and tested as in A (2) (Defective Contacts).

B (6.) *Disconnections in Armature Circuit.*—If there is a broken circuit in the armature, as sometimes happens, through a fracture of the armature connections, &c., there will be serious flashing or sparking at the brushes, which cannot be suppressed by adjusting the rocker. As a rule it results in the production of "flats" upon one or more bars of the commutator. If it is impossible to stop the machine, the sparking may be much reduced by placing one of the brushes in each set a little in advance of the others, so as to bridge across the disconnection. If the machine is only provided with one brush on each side of the commutator, a bit of copper wire may be fixed in each holder, so as to project slightly in front of the

brushes, and thus bridge over the broken circuit. The localisation and repair of this fault is described in Chapter XII. (Faults in Armatures).

B (7.) *Short Circuits in Armature Circuit.*—This fault is indicated by sparking at the commutator, and in bad cases by an excessive heating of the armature, dimming of the light, and slipping of the belt, and in the case of drum armatures by a sudden cessation of the current. The localisation and repair of the different classes of short circuits is referred to in the succeeding chapter (Faults in Armatures).

B (8.) *Short Circuits or Disconnections in Field Magnet Circuit.*—Either of these faults is liable to give rise to sparking at the commutator. If one of the coils is short circuited, the fact will be indicated by the faulty coil remaining cool while the perfect coil is overheated. The fault may arise through some of the connections to the coils making contact with the frame of the machine or each other. To ascertain this, examine all the connections, and test with a battery and galvanometer in the manner described in A (2), A (6), A (11). A total disconnection in one or more of the field coils may readily be detected by means of the battery and galvanometer. A partial disconnection is not, however, so readily discovered, for the reason that the coil wires may be in sufficiently close contact to give a deflection of the galvanometer needle. The only methods of detecting this fault is by measuring the resistance of the coils with an Ohmeter or Wheatstone Bridge, or by placing an ammeter in circuit with each coil in turn, and comparing the amount of current flowing in each. If the short circuit is not accessible, the only way to remedy

the fault is to re-wind the coil, and the same applies to a disconnection if in the interior of the coil.

C. **Excessive Heating.**—The excessive heating of the constituent parts of a dynamo is probably the most common and at the same time the most annoying fault which arises in the working of a dynamo. In a modern machine the temperature of none of the constituent parts ought to exceed 80° Fahr. above the surrounding air, and in the case of the bearings, this temperature ought not to be reached under normal conditions of working. If this limit is exceeded after a run of six hours or less, it indicates a machine either badly designed and probably with the material cut down to the lowest possible limit with a view to cheapness, or some fault or other which should be searched for and remedied as early as possible, otherwise the machine will probably be destroyed. The heating may be due to various causes, electrical or mechanical; and may occur in any one or more of the component parts of the dynamo, viz.:—

(1.) Connections.
(2.) Armature, commutator, brushes.
(3.) Field magnets.
(4.) Bearings.

It may be detected by applying the hand to the different portions of the machine if low tension, or a thermometer if high tension, as directed in Chapter X. (Running Dynamos), and also by a smell of overheated insulation and paint or varnish. When this last indication is felt, it is advisable to stop the machine at once, otherwise the insulation is liable to be destroyed.

C (1.) *Heating of Connections.*—This may proceed from either or both (*a*, *b*) of the following causes:—

(*a*) *Excessive Current.*—The terminals and connections will be excessively heated if a larger current passes through them than they are designed to carry. This nearly always proceeds from an overload of the dynamo, and if this is rectified as directed in B (4) (Overload of Dynamo), the heating will disappear.

(*b*) *Bad Contacts.*—If the contacts of the different connections of the dynamo are not kept thoroughly clean and free from all grit, oil, &c., and the connections themselves are not tightly screwed up, great heating will result, and they may even be unsoldered.

C (2.) *Heating of Armature, Commutator, and Brushes.*—When excessive heating occurs in these portions of the dynamo, it may proceed from any of the following causes:—(*a*) Excessive current; (*b*) Heated bearings; (*c*) Short circuits in armature or commutator; (*d*) Moisture in armature coils; (*e*) Disconnections in armature coils; (*f*) Eddy currents in armature core or conductors.

(*a*) *Excessive Current.*—When the dynamo is overloaded, the temperature of the armature will rise to a dangerous extent, depending upon the degree the safe capacity of the machine is exceeded, and heavy sparking of the brushes will also result. If the overload is not removed as directed in B (4) (Overload of Dynamo), the insulation of the armature may be destroyed.

(*b*) *Heated Bearings.*—If the bearings are heated, the heat may be conducted along the armature shaft and core, thus giving rise to excessive heating of the armature. In this case the source of the heating may

be located and remedied as directed in C (4) (Heated Bearings).

(*c*) *Short Circuits in Armature or Commutator.*—This fault results in sparking at the brushes, and in excessive heating of one or the whole of the armature coils, and even in the burning up of the latter if a bad case. When the armature is overheated, and the defect does not proceed from an overload or the causes mentioned below, the dynamo should be immediately stopped and tested for this fault as directed in Chapter XII. (Faults in Armatures).

(*d*) *Moisture in Armature Coils.*—The presence of moisture in either the armature or field coils will give rise to excessive heating, since the effect is to produce a partial short circuit. This fault generally occurs when the machine has been standing idle for some time in a damp engine room, and in many cases the insulation has been entirely destroyed through incautious starting of machines at full speed under these conditions. The moisture may be dissipated by keeping the machine running at a moderate pressure until thoroughly dry. Machines of American and Continental make are particularly liable to this fault, owing to the use of hygroscopic materials for the insulation of the various parts, such as the commutator, armature core and field coils, flanges, &c.

(*e*) *Disconnections in Armature Coils.*—This fault results in local heating of the armature, for the reason that resistance is interposed in the path of the current at the fracture. It always results in sparking at the brushes, and the heating being confined to the neighbourhood of the disconnection, this latter may easily be located by this indication, or by

the methods described in Chapter XII. (Faults in Armatures).

(*f*) *Eddy Currents in Armature Core or Conductors.*—When the construction of the armature core and conductors does not fulfil the necessary conditions required for the prevention of eddy currents, such as the laminations not being sufficiently insulated or numerous enough, a great heating of the whole o. the armature results, which may even extend to the bearings. This fault being due to bad construction of the core, there is no remedy for it other than the purchase of a new armature, or the entire reconstruction of the old. The fault may be detected by exciting the field magnets and running the machine on open circuit, with the brushes raised off the commutator for some time, when the armature will be found to be excessively heated uniformly in all parts.

C (3.) *Heating of Field Magnets.*—When the field magnets are found to be excessively heated, they should be tested for the following faults in the order given :—(*a*) Excessive exciting current; (*b*) Moisture in field coils; (*c*) Short circuits in field coils; (*d*) Eddy currents in pole pieces.

(*a*) *Excessive Exciting Current.*—When the excessive heating arises from this cause, all the exciting coils will be heated equally. It may be due to excessive voltage, in the case of shunt dynamos; or to an overload in the case of compound and series dynamos. In either case it may be remedied by reducing the voltage or overload as directed in B (4) (Overload of Dynamo). If due to the coils being incorrectly coupled up, *i.e.*, coupled up in parallel in

place of series, it will be necessary to rectify the connections or insert a resistance in series.

(*b*) *Moisture of Field Coils.*—As in the armature, the presence of damp or moisture in the field coils tends to decrease the insulation resistance, thus in effect producing a short circuit with its attendant heating. The fault may easily be detected by applying the hand to the field coils, when they will be found to be damp, and in addition steam or vapour will be given off where the machine is working. The fault may be remedied by drying and varnishing the coils as directed in "Moisture in Armature Coils."

(*c*) *Short Circuits in Field Coils.*—This fault is characterised by an unequal heating of the field coils. If the coils are connected in series, the faulty coil will be heated to a less extent than the perfect coils. If, on the other hand, they are connected in parallel, the faulty coil will be heated to a greater extent than the perfect coils. The faulty coil can thus be easily located by this indication, and also by measuring the resistance of each with an Ohmeter or Wheatstone Bridge.

(*d*) *Eddy Currents in Pole Pieces.*—This fault may be due to defective design or construction of the armature. Toothed core armatures are particularly liable to cause this fault, if the teeth and air gap are not properly proportioned. The defect may also be occasioned by variation in the strength of the exciting current. If due to this latter cause, it will be accompanied by sparking at the brushes. If a shunt dynamo, insert an ammeter into the shunt circuit, and note if the deflection is steady. If this is not the case, the variation in the current most probably pro-

ceeds from imperfect contacts thrown into vibration. These can be remedied as in A (2) (Defective Contacts).

C (4.) *Heating of Bearings.*—The heating of the bearings is of frequent occurrence in the working of dynamos, and is probably the most troublesome fault to which they are subject, as its origin is, as a rule, obscure. It is particularly liable to occur in cases where a heavy flywheel is fitted on the armature spindle or shaft, as is usually the case when the machine is driven by a gas or oil engine. In such cases, unless the pulley bearing is specially proportioned to carry the extra weight, and this, in the cheaper class of dynamo, is frequently not the case, the machine ought to be provided with a third bearing, so that the flywheel is not "overhung."

When the bearings are found to heat excessively so that the heat cannot be borne by the naked hand, and such simple remedies as the supply of fresh lubricant, or slacking back the caps of the bearings or the belt fails to remedy the trouble, the dynamo should be stopped, as it indicates something radically wrong. The use of water on heated bearings has been recommended, but its use is questionable. No doubt it cools the bearings for the time being, and allows of the machine being run for a short time longer; but when the bearings are in such condition as to need the application of water, probably as much damage is done to the journals and liners, through scoring, &c., as more than counterbalances any slight gain secured through running the machine while the bearings are heated. Removing the lubricators, and flooding the bearings and journals with ordinary or castor oil, tends

to reduce the heating; or the effect of sulphur mixed with oil, and applied *direct* to the bearings, after removing the lubricators, should be tried. If these remedies fail, the machine should be stopped, and the cause of the heating ascertained. As a rule, heating of the bearings is due to—(*a*) Defective lubrication or bad oil; (*b*) Journals too tight; (*c*) Belt too tight; (*d*) Dirt, grit, &c., in bearings; (*e*) Rough or badly fitted journals or bearings; (*f*) Bent or badly turned shaft; (*g*) End pressure of shaft against bearings; (*h*) Armature incorrectly placed in armature chamber; (*i*) Badly proportioned bearings; (*j*) Bearings out of line; (*k*) Conduction of heat from armature.

(*a*) *Defective Lubrication or Bad Oil.*—When the bearings heat up, first examine the lubricators to see that they are full, and that they feed the lubricant properly, and that none of the feed or waste oil passages are clogged. It is advisable to pass the end of a piece of wire down each of the passages occasionally to clear them. The quality of the oil supplied to the lubricators should be of the best mineral oil, perfectly clean and free from grit. It is advisable not to use the waste oil for the dynamo again; but if used, see that it is well filtered. In some instances, hot bearings, due to defective lubrication, have been remedied by cutting grooves obliquely in the face of the liners for the better circulation of the oil.

(*b*) *Journals too tight.*—If the caps of the bearings are screwed up too tight, the bearings are bound to heat up. As the armature spindle or shaft is not subjected to any reciprocal stresses, it is only needful to have the caps of the bearings screwed up hand

tight. If the top brass does not bear upon the bottom brass, it may be necessary to scrape open the bearing a little, or insert a liner between the top and bottom brasses, until the spindle revolves freely by hand.

(*c*) *Belt too tight.*—Heating of the bearings may be due to too great a tension of the belt, caused either by an overload of the dynamo, or through too narrow a belt being used for the work, thus necessitating the dynamo being screwed up tightly upon the slides. When this is the case, the bearing next the pulley will be heated more than the other. The remedy is to reduce the load upon the dynamo, as directed in B (4) (Overload of Dynamo), or get a broader belt and pulley and run with some slack on the belt.

(*d*) *Dirt, Grit, &c., in Bearings.*—The presence of the smallest quantity of grit in the lubricant or bearings will result in great heating of the latter, and in scoring of the shaft and liners, if not removed quickly. The machine should be stopped if possible, and the caps of the bearings taken off and the armature taken out of the bearings, and the latter carefully cleaned and scraped up smooth. If the journals are scored to any extent, it will be necessary to put the armature in the lathe and carefully file them up with a dead-smooth file before replacing. If the machine cannot be stopped at once, the lubricators should be made to feed very fast, or removed entirely, and the bearings continuously flooded with oil by means of an oil can until the machine can be conveniently stopped.

(*e*) *Rough or Badly Fitted Journals or Bearings.*—To ensure cool running, the journals should be per-

fectly smooth and true, and bear upon the surface of the liners throughout their entire length and width. To ascertain if this is the case, the caps of the bearings should be removed, and a little "marking," composed of red lead or other colouring matter and ordinary oil, rubbed upon the journals. The caps should then be replaced, and the nuts screwed up to working pressure, and the armature rotated a few times. The caps should then be again removed, and the armature taken out, and the bearings examined. If the journals are bearing all over the surface of the liners, the fact will be indicated by the marking being distributed equally all over. If this is not the case, the projecting portions of the liners, as indicated by the marking, should be carefully scraped up and the armature put back again, and the bearings tested from time to time until the journals bear all over as indicated by the marking being equally distributed all over the surface of the liners.

(*f*) *Bent or Badly Turned Shaft.*—A bent shaft can be detected by rotating it with the hand. If bent, it will "bind" at some portion of the revolution. If only slightly bent, the shaft should be placed in the lathe and carefully sprung back approximately straight, a light cut being taken off the journals to finally true it. The bearings will then need to be carefully refitted, as directed above. If badly bent, the only remedy is a new one. A badly turned shaft may be detected by means of the calipers and marking, as described above. If not truly circular, the marking will be unequally distributed over the *journals.*

(*g*) *End Pressure of Shaft against Bearings.*—This

may be caused either by the shaft not being truly level, or through the belt not being truly aligned, or through there being no "end play." In the former case, carefully test the journals with a spirit-level, and pack up the dynamo or slide rails until perfectly level. If the belt does not run true upon the pulleys, it will be necessary to align the machine by moving it upon the sliding bedplate until the centre of the belt runs upon the centre of the pulley. If no end play exists, the shaft will be bound between the collars and the bearings, and the defect will be visible to the eye. The correct amount of end play required varies with the size of the dynamo and method of driving adopted. In direct driven dynamos, if the collars of the journals are clear of the ends of the bearings, no end play is needed. In belt-driven dynamos, in order that the brushes may not wear ruts in the commutator, it is necessary to have from one-eighth to one quarter of an inch of end play. In all cases it may be ascertained if the correct amount of end play is present by running the dynamo and observing, when *slight* pressure is applied to one end of the shaft, if any end motion is produced. If no end motion is obtained, or a strong pressure is needed to obtain the latter, the face of the collar or end of the bearing against which the shaft bears should be filed or turned down, until the correct amount is obtained, when the machine is running.

(*h*) *Armature incorrectly placed in Armature Chamber.*—When the field magnet of a dynamo is excited, it has a tendency to attract the iron core of the armature. The direction and intensity of the attractive force varies with the type of field magnet and the position of the armature core in the armature chamber

or bore. In vertical horse-shoe magnets of the overtype form (Fig. 61), if the armature is placed exactly in the centre of the armature chamber, there is a tendency for the armature to be attracted downwards, the intensity of the attraction varying with the strength of the field magnets. In large dynamos this attractive force may even amount to some thousands of pounds, and therefore, if the armature core is not placed in the armature bore in such position as to balance or nullify the attractive force, the bearings are liable to heat up through the excessive pressure brought to bear upon them. To counterbalance the attractive force, it is necessary in such dynamos to place the armature slightly above the centre of the armature chamber. In field magnets of the undertype form (Fig. 62), the attraction is in an upward direction, and therefore, as the weight of the core is lifted off the bearings, the latter are not so liable to heat up as in the case with the overtype form. In horizontal field magnets (Figs. 63 and 64), the attractive forces act in opposite directions, and are therefore balanced; and in such dynamos the armature core may be placed exactly in the centre of the armature bore. A heating of the bearings is also liable to be occasioned through the attractive forces developed by the centre of the armature core not being parallel with the centre of the armature chamber or bore, or through the core being nearer one pole piece than the other. This may result from unequal wearing of the bearings, and therefore the bearings should either be re-lined or the bolt holes of the bearings readjusted, or the bearings packed up until the armature is correctly centred.

(*i*) *Badly Proportioned Bearings.*—The bearings will heat up if the wearing and heating surfaces are not suitably proportioned for the work they have to perform. In such cases the bearings will heat at the first run of the machine. The only remedy is to put in new or larger bearings, or an additional one, if the shaft is long enough, and arrangements can be made to admit of this being done, but a machine possessing these characteristics ought not to be accepted from the makers.

(*j*) *Bearings out of Line.*—This will be indicated by an unequal wear of the liners, and by the shaft binding or seizing. The remedy is to draw the bolt holes of the bearings until the bearings are correctly aligned with each other and with the armature bore.

This fault is not liable to occur if the bearings are provided with spherical or self-aligning brushes, as they ought to be if the machine is of modern construction.

(*k*) *Conduction of Heat from Armature.*—The bearings are liable to heat up through the heat developed by an overload or short circuit of the armature, or the production of eddy currents in the core being conducted along the shaft. If due to this cause, the indications and remedies will be as in B (4) (Overload of Dynamo), B (7) (Short Circuits in Armature), C (2) (Heating of Armature, &c.).

D. **Excessive Noise or Vibration.**—A well constructed and attended dynamo, not being subjected to any reciprocal stresses, ought to run with an exceedingly small amount of noise, merely a slight hissing, due to the pressure of the brushes upon the commutator; if an excessive noise or vibration becomes apparent, the causes tending to produce it are:—

(1.) Bad foundations.
(2.) Loose screws, connections, &c.
(3.) Belt joints.
(4.) Bad adjustment of brushes.
(5.) Knocking of shaft or pulley against bearings.
(6.) Armature out of balance.
(7.) Armature knocking or rubbing against pole pieces.
(8.) Straining of shaft couplings.

D (1.) *Bad Foundations.*—A bad foundation will result in a continuous vibration being set up, and in a greatly increased wear of the commutator and brushes. The foundation should not only be constructed of good and sound materials, but care should be taken that it is carried far enough down to secure a good bottom.

D (2.) *Loose Screws, Connections, &c.*—Examine and screw up tight all screws and bolts liable to slack back.

D (3.) *Belt Joints.*—When the belt is roughly or badly jointed, a noise and vibration is set up as it passes over the pulley. The only remedy is to make a new joint. The efficient working of the dynamo depends in a large measure on the jointing of the belt. Care should therefore be taken in this respect. The belt should be soft and pliable, and the joint should if possible be a long spliced joint, or a butt joint secured with fasteners. A lap joint ought not to be used under any circumstances.

D (4.) *Bad Adjustment of Brushes.*—When this is the case, or when the commutator is in bad condition, or the brushes too hard, a singing or hissing noise is

produced at the commutator. The defect may be remedied by adjusting the pressure of the brushes upon the commutator, or by a little lubrication of the latter with vaseline or oil, or by filing or turning down the commutator if in very bad condition.

D (5.) *Knocking of Shaft or Pulley against Bearings.*—This is produced when the shaft has too much end play. To remedy, insert a thin washer or two between the collar of the shaft and the end of the bearing, or between the pulley and the bearing.

D (6.) *Armature out of Balance.*—When this is the case violent vibrations are produced, which vary with the speed of the dynamo. To remedy, the armature should be taken out of the machine, and the journals of the shaft mounted upon two perfectly level knife edges, or, if these are not obtainable, upon two wooden battens fixed edge upwards and very carefully levelled either way. If the armature, when thus mounted, be given a slight motion either way, the heavier side will have a tendency to descend, by which it may be discovered. To balance, it will be necessary to drill a few holes in the heavier side of the pulley, or fix a lead weight upon the inner side of the rim of the pulley on the lighter side.

D (7.) *Armature Knocking or Rubbing against Pole Pieces.*—This may be recognised by the scraping noise produced while the machine is running. It may be caused by the bearings wearing down too far, or through a defective or loose winding. The bearings should first be examined, and if necessary new liners run in or the bearings packed up. If not due to this cause, the armature should be carefully examined to see if any portion of the winding projects,

and that it is securely fixed. Any projecting portion of the winding should be carefully beaten down with a mallet, and if necessary new binding wires wound upon the armature to secure the windings in position. If it is found impossible to level down the projecting portion of the winding, the parts of the pole pieces against which it rubs should be filed or chipped away.

D (8.) *Straining of Shaft Couplings.*—When the armature is coupled direct to the engine crank-shaft, and the wear of the bearings is unequal, a straining of the coupling sometimes results which produces a noise. The remedy is to re-line and re-adjust the bearings. In many cases a flexible coupling is provided to prevent this occurring.

E. **Variation or Decrease of Speed.**—This will be indicated by the dynamo failing to excite, or by a decrease of the voltage if the machine is working The fault may proceed from the undermentioned causes:—

(1.) Reduced speed of driving engine.
(2.) Overload of dynamo.
(3.) Defective bearings.
(4.) Short circuits in armature.
(5.) Armature rubbing against pole pieces.
(6.) Slack or dirty belt.

E (1.) *Reduced Speed of Driving Engine.*—It can readily be ascertained whether the alteration in speed of the dynamo proceeds from this cause by counting the revolutions of the engine with a speed counter. If at any time it is necessary to run an engine driving a shunt or compound dynamo at a lower speed than the normal, the voltage and output of the dynamo can generally be maintained at their ordinary value

by coupling up the shunt coils in parallel, thus increasing the strength of the current flowing in the shunt circuit and the strength of the field correspondingly. Care should be taken, however, that the coils do not overheat with the increased current. If this occurs, insert a resistance in series with the shunt circuit.

E (2.) *Overload of Dynamo.*—When the reduction in speed proceeds from this cause, it is accompanied by excessive sparking at the brushes, and heating of the bearings and armature, and slipping of the belt. If the overload be removed as directed in B (4) (Overload of Dynamo), the speed will again attain its normal value.

E (3.) *Defective Bearings.*—When due to this cause, the bearings will be excessively heated, and the shaft will "bind" or "seize," making a noise. It generally proceeds from defective lubrication, and may be remedied as directed in C (4) (Heating of Bearings).

E (4.) *Short Circuits in Armature.*—This practically amounts to an overload of the dynamo, and is accompanied by sparking at the brushes, heating of dynamo, and reduction of speed. The short circuit should be localised, and repaired as directed in Chapter XII. (Faults in Armatures).

E (5.) *Armature Rubbing against Pole Pieces.*—This will result in a diminution of speed if not remedied. The fault may be repaired as directed in D (7).

E (6). *Slack or Dirty Belt.*—If the driving belt is not kept in good order, and free from oil, dirt, &c., a considerable amount of power will be lost in transmission. This will also be the case if the tension of

the belt is not properly adjusted. If the motor driving the dynamo is a steam engine, turbine, or other steady running motor, the belt should in all cases be as tight as possible, consistent with the temperature of the bearings. In the case of gas or oil engines, however, it will be necessary to have a certain amount of slack on the belt to allow of a little slip on the dynamo pulley, the amount varying with the irregularity of speed of the driving motor.

F. Variation of Voltage.—The pressure at the terminals of either shunt, series, or compound dynamos is liable to vary or fluctuate from various causes. In plain shunt or series wound dynamos a variation of pressure under a varying load follows as a consequence to the construction of the machine. A distinction, therefore, needs to be drawn between this natural variation of pressure and an abnormal fluctuation, which also affects compound dynamos, which may occur from time to time in the working of such machines. The causes tending to produce a fluctuation of voltage are:—

(1.) Irregularities of speed.
(2.) Bad joints in belt.
(3.) Short circuits or disconnections in armature circuit.
(4.) Short circuits or disconnections in field magnet circuit.
(5.) Incorrect connections.

F (1.) *Irregularities of Speed.*—Any cause tending to produce a variation in the speed of the dynamo such as is comprised under Section E (Variation of Speed), is responsible for a variation of voltage. Steam engines, turbines, &c., give as a rule very

little trouble in regard to irregularities of speed. In the case of gas and oil engines, however, an unsteadiness of speed is always present, owing to their mode of action and construction. Before such motors can be used successfully in driving dynamos, this unsteadiness of speed needs to be reduced and compensated as far as possible. With this object, such engines, when used for driving dynamos, are therefore fitted with extra heavy fly-wheels, and a fly-wheel is also fitted upon the armature spindle of the dynamo. In driving with such engines, the governors and valves are adjusted, if possible, to give an explosion at every revolution of the fly-wheel, and any little irregularity of speed is then compensated by varying the tension and slip of the belt on the dynamo pulley.

F (2.) *Bad Joints in Belt.*—If the belt is not jointed in a suitable manner, it will cause a fluctuation of voltage, and a flickering of the light as the joint passes over the pulley. The belt should in all cases be soft and pliable, and made endless by a long spliced joint, or a butt joint with fasteners, or an endless link belt should be used. Lapped joints should on no account be used.

F (3.) *Short Circuits or Disconnections in Armature Circuit.*—When either of these faults is present, a periodical fluctuation of voltage will be set up, accompanied by sparking at the brushes. When this occurs the machine should be stopped at once, and the fault located, and repaired as directed in Chapter XII. (Faults in Armatures).

F (4.) *Short Circuits or Disconnections in Field Magnet Circuit.*—Either of these faults will give rise to a diminution or increase of voltage. To locate

the faults, the entire field circuit should be tested and examined as described in Sections A, B, and C.

F (5.) *Incorrect Connections.* — If on starting a machine for the first time, or after repairs, the voltage is either above or below its normal value, it is possible the variation may be the result of incorrect connections. The whole of the connections, including the armature, brushes, flexible leads, and field coil connections, should therefore be examined and verified. In a compound wound generator the connecting of the series coils in opposition to the shunt winding results in an abnormal variation of voltage, which may be detected by the fall in pressure as the load comes on. The fall in pressure will be considerably more than if the machine was a purely shunt wound one, whereas if the windings were connected correctly, the voltage would, of course, rise if over-compounded, or be maintained constant if an ordinary compound winding.

CHAPTER XII.

FAULTS IN ARMATURES.

THE armature and commutator are the most vulnerable parts of a dynamo, and being subjected whilst rotating to various detrimental influences, are a prolific source of faults, the chiefest of which may be enumerated as follows :—

(1.) Short circuits in armature.
(2.) Grounds in armature.
(3.) Disconnections in armature circuit.
(4.) Flats on commutator.
(5.) Short circuits in commutator.
(6.) Rough and uneven surface of commutator.
(7.) Segments loose or knocked in.

(1.) **Short Circuits in Armatures.**—The classes of short circuits which occur in the armature are—(*a*) Short circuits in individual sections or coils; (*b*) Short circuits between adjacent coils; (*c*) Short circuits between sections through frame or core of armature; (*d*) Short circuits between sections through binding wires; (*e*) Partial short circuits in armature.

(*a*) *Short Circuits in Individual Sections or Coils.*—This is an exceedingly common fault, which makes its presence known by a violent heating of the armature,

flashing at the commutator, flickering of the light, and by a smell of burning varnish or overheated insulation. When these indications are present, the machine should be stopped at once, otherwise the armature is liable to be burnt out. The fault is due either to metallic dust lodging in the insulation between adjacent bars of the commutator, or to one or more convolutions of the coils coming into contact with each other, either through a metallic filing becoming embedded in the insulation or damage to the insulation. When the machine is stopped, the faulty coil, if not burnt out, can generally be located by running the fingers over the armature, by its excessive temperature over the rest of the coils, and by the baked appearance of the varnish or insulation. If the machine will not build, and it is suspected that the fault arises from short circuited armature coils, the field magnets should be excited by the current from a storage battery or another dynamo, and having raised the brushes from contact with the commutator, the armature should be run for a short time. In stopping, the faulty coil or coils may be located by the heat generated by the short circuit. When the dynamo is started to localise a short circuit, great precautions should be taken, and the machine only run for a few minutes at a time until the faulty coil is detected. A short circuited coil may also be located by the fall of potential method. Fig. 99 illustrates diagramatically this method of testing. Disconnect the external and field circuits from the armature, and pass a large current —say from 20 to 100 amperes—from a battery (B) or another dynamo through the whole armature by

means of the brushes. Then, having previously well cleaned the commutator, measure the difference of potential between adjacent segments all round

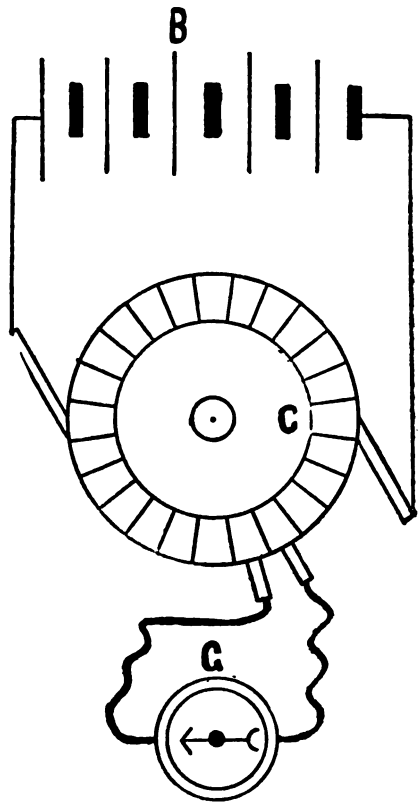


FIG. 97.

the commutator (C), by means of a voltmeter or galvanometer (G), the terminals of which are connected to adjacent segments, as shown. The short

circuited coil or coils will be located by the difference of potential between the corresponding segments being little or nothing. It may be remarked, however, that this is not always a decisive test. In some cases the short circuit may be intermittent, or may disappear as soon as the armature ceases to rotate. In such cases, the short circuit is caused by the wire coming into contact through the action of the centrifugal forces developed by the rotation of the armature. The former test is therefore the more reliable in all cases. When the faulty coil has been located, the insulation between the segments of the commutator to which its ends are connected should be carefully examined for anything that may bridge across from plate to plate, and scraped clean from any adherent metallic particles or burrs. If the commutator is apparently all right, the fault probably lies in the winding. The insulation of this should be carefully examined, and any metallic filing or other particle discovered therein carefully removed, and a little shellac varnish applied to the faulty part. It will sometimes happen that a small portion of the insulation has been abraded from two adjacent conductors, thus causing them to come into electrical contact with each other. In such circumstances a small boxwood or other hardwood wedge, coated with shellac varnish, and driven in tightly between the wire, will generally effect a cure. If the faulty coil cannot be expeditiously repaired, and the dynamo is urgently wanted, the coil may be cut out of circuit altogether, and the corresponding commutator segments connected together with a piece of wire, of a size proportionate to the amount of current to be carried,

soldered to each. It will not be necessary to cut out and remove the entire coil. If the active portions only are separated from one another, so that they do not for a closed circuit, it will answer the purpose—*e.g.* if the wires are cut with a chisel at the point where they pass over the ends of the core, and the ends separated, it will be quite as effective as removing the entire coil. It is wise, of course, to rewind the coil at the first opportunity.

(*b*) *Short Circuits between Adjacent Coils.*—Whilst in the ring armature the presence of this fault does not necessarily imply that the machine will not build, in the drum armature wound into a single layer of conductors it entirely prevents this occurring. Reference to Fig. 23 will show that adjacent coils are during a certain period of the revolution at the full difference of potential generated by the machine. Hence, if any two adjacent coils are connected together or short circuited, the whole of the armature will be practically closed on itself, any current generated flowing within the armature only, without passing to the external circuit. Large drum armatures wound with compressed and stranded bars and connectors are particularly susceptible to this fault, a slight blow generally forcing one or more of the strands into contact with the adjacent bars, thus short circuiting the armature, and rendering it practically useless so far as the generation of current is concerned. In this class of short circuit in drum armatures, the method of locating the faulty coils by exciting the field, and running the armatures on open circuit, is not applicable, for the reason that the whole armature will be heated equally. Mr Loomis, in the

Electrical Engineer of New York, has described a method of locating faults of this description, and, as it appears reliable, it is given below. "In following this plan, no arrangement for belting need be made. It is only necessary to fasten a monkey wrench to the rim of the pulley, or, better still, a crank to the shaft. Now, excite the fields, and, to make the effects more marked, connect the coils in parallel, as the excessive current will only be used for a moment. When this has been done the strongest man will scarcely be able to rotate the armature, and then only with extreme slowness, except at one position. When this position has been

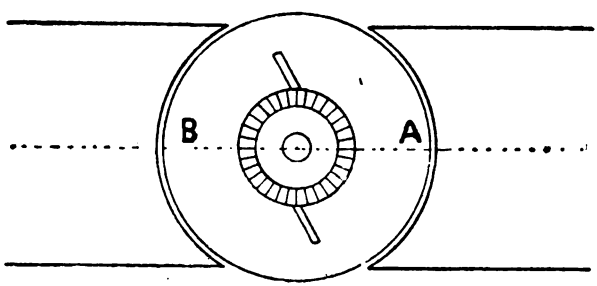


FIG. 98.

found, mark the armature at points in the centre of the pole pieces (A B), as shown in the accompanying diagram (Fig. 98), and at both ends of the armature. The explanation is that both halves of the armature oppose one another at this position; but when not at these points a continuous circuit is formed, and the resultant magnetic effect is enormous. As the "cross" or "short" circuit will be found at one of these four marked points, it becomes desirable to know in which one it is most likely to be found. Experience has shown that it is

nearly always on the commutator end in the last half of the winding, where the wires pass down through the first half terminals. This applies to an unequal winding. In armatures where the windings are equal, it is as liable to occur at one point as at another. With this method a defect can be found and remedied in a few moments, for it has always been a simple matter to repair it when discovered. These results can be observed in a perfect armature by connecting the opposite sections of the commutator. The above will be understood to apply to armatures having Siemens winding." Faults of this description can frequently be discovered by a careful inspection of the windings of the armature without recourse to testing. When located, the fault can usually be repaired with a hardwood wedge, as explained above, or a piece of mica or vulcanised fibre cemented in place with shellac varnish.

(*c*) *Short Circuits between Sections through Frame or Core of Armature.*—The localisation of this fault can be effected by the methods described above, and by disconnecting the whole of the armature coils from the commutator and from each other, and testing each separately with a battery and galvanometer coupled up as in Fig. 93, one wire being connected to the shaft and the other to the end of the coil under test. As a rule, there is no way of remedying this fault other than unwinding the defective coils, reinsulating the core, and rewinding new coils.

(*d*) *Short Circuits between Sections through Binding Wires.*—This fault is the result of a loose winding, and is caused by the insulation upon which the binding wires are wound giving way, thus bringing coils

at different potentials together. As a consequence to the heavy current which flows, the binding wires are as a rule unsoldered or burned. The location of the fault can therefore be effected by simple inspection. To remedy, it will be necessary to unwind and rewind on new binding wires, on bands of mica or vulcanised fibre, soldering at intervals to obviate flying asunder.

(*e*) *Partial Short Circuits in Armatures.*—This is, as a rule, due to the presence of moisture in the windings. To remedy, the armature should be taken out and exposed to a moderate dry heat, or subjected to a current equal to that ordinarily given by the dynamo. Under the action of heat or of this current the moisture will be gradually dispersed. When thoroughly dry, and whilst still warm, a coat of shellac or rubber varnish should be applied to the whole of the windings to prevent further access of moisture.

(2.) **Grounds in Armatures.**

(*a.*) *Armature Coils grounded or connected to Core or Frame of Armature.*—When this fault is confined to a single coil, it is not in itself liable to do any damage. If, however, a similar fault develops in some other part of the dynamo, or in the external circuit, the coil is liable to be burned out. Mr F. Bain, in the *Western Electrician*, has described a simple method of locating a coil grounded to the frame of an armature, which is reprinted below. Fig. 99 clearly shows the arrangements of the details. B is a battery or dynamo circuit, giving a current of a few amperes through the armature by its own brushes (1 and 2). At A, a roughly-made galvanometer, to carry some 25 amperes or so, is placed, one terminal being in connection with the shaft of the armature, and the

other attached to a movable brush (3). Since the function of the particular galvanometer is simply to show a deflection when a current is passing, and to mark zero when there is none, a coil of thick wire, with a pocket-compass in the centre, will do all that is required, but care must be taken to remove it sufficiently far away from the disturbing effects of the armature magnetism. The manner of testing is as follows:—Assume a steady current to be flowing

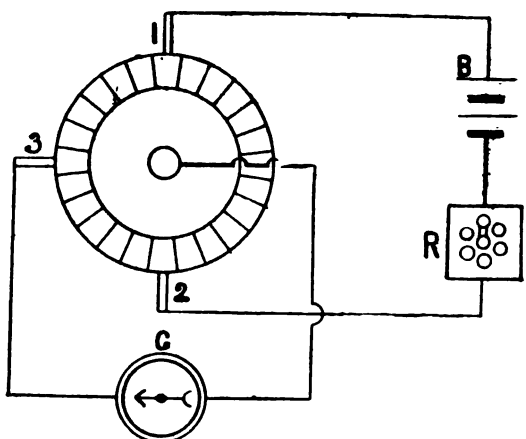


FIG. 99.

from battery (B) through the armature, touch the commutator with brush (3), and a current will flow through (G). Slowly rotate the armature or the brush (3), until the galvanometer (G) shows no deflection. The coil in contact with 3 will be found to be *grounded* or connected to the frame. A hand regulator or rheostat (R) may be inserted in series with the battery or dynamo circuit to regulate the strength of the current passing. The main advantage of this test is that the damaged

coil can be located without unsoldering the coils from the commutator, which is sometimes a difficult operation without proper tools; and further, the fault can frequently be repaired without disconnecting any of the wires if its exact position be determined.

(3.) **Disconnections in Armature Circuit.**—A partial or complete disconnection in the armature circuit is always characterised by heavy sparking at the commutator, but not, as a rule, by an excessive heating of the armature or slipping of the belt, and this enables this fault to be distinguished from a short circuit. The faulty part can always be readily located by the "flat" which it produces upon the surface of the commutator. The armature circuit being open at the faulty part, heavy sparking results at every half revolution as the brushes pass over it, and as a consequence the corresponding segments are "pitted" or "flattened" with respect to the others, and may easily be discovered on examination. The fault may occur in either the commutator or in the coils of the armature. To ascertain whether it is in the latter, carefully examine the winding of the faulty coil. The defect may be sought for more particularly at the commutator end of the armature, as breaks in the wire are most frequent where the connections are made with the commutator segments. If no break can be discerned, try passing a heavy current through the faulty coil by means of the brushes. If a disconnection exists in sufficient contact to pass a current, the coil will be heated in the neighbourhood of the disconnection, and may be discovered by running the fingers over the coil. When located, the fault may be repaired by rewinding the coil, or carefully

cleaning the broken ends and jointing. The fault may also be temporarily repaired by soldering the adjacent commutator segments together without disconnecting the coil.

(4.) **Flats on Commutator.**—This is the name given to a peculiar fault which develops on one or more bars of the commutator. It is not confined to dynamos of bad design or construction, but frequently appears on those of the highest class, and may be recognised as a "pitting" or "flattening" of one or more segments. It is always accompanied by sparking at the brushes, and may be due to a periodical jumping of the brushes, caused by a bad state of the commutator, or a bad joint in the driving belt, or to a flaw, or a difference in the composition of the metal of the particular bar upon which it appears. But more frequently it may be traced to a more or less developed fault, such as a disconnection, either partial or complete, in the armature coil. The disconnection may occur either in the coil itself, or at the point where its ends make connection with the lug of the commutator, or at the point where the lug is soldered to the segment of the commutator. To remedy the fault, the brushes should be examined to see if any periodical vibration takes place. If such is the case, the cause should be removed, and the flat carefully filed or turned out, and the brushes readjusted. If it is due to a difference in the composition of the metal of which the segment is made, the flat will exist as long as the particular segment is in use, and will need to be periodically turned out if a new segment is not fitted into the commutator. Now that the construction of commutators has been

improved, however, by the use of hard-drawn copper or phosphor-bronze segments, this fault is rarely due to this last-mentioned cause. It is more frequently due to bad soldering, or jointing of the conductors to the lugs, or of the lugs to the segments. In all cases of flats, if the disconnection in the armature circuit is not complete, and cannot be readily located, the effect of re-soldering or sweating the ends of the coils into the lugs should be tried. Flats may also frequently be cured by drilling and tapping a small hole in the junction between the lug and the segment, and inserting a small screw, or bit of screwed copper

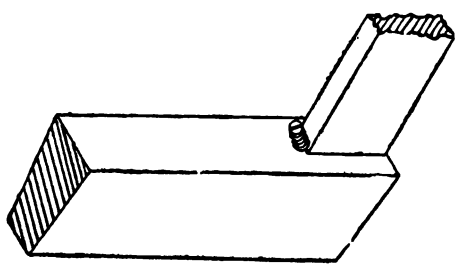


FIG. 100.

or brass wire, as shown in Fig. 100, afterwards filing down level with the surface of the commutator.

(5.) **Short Circuits in Commutator.**—These are of frequent occurrence, and result in heating of the armature and sparking at the brushes. They are caused either by metallic dust or particles lodging in the insulation between the segments, or by the deterioration of the commutator insulation. To remedy, the insulation between the segments should be carefully examined, and any metallic dust, filings, or burrs cleaned or scraped out. When the com-

mutator is insulated with asbestos or pasteboard (as is oftentimes the case in dynamos of continental make), short circuits very frequently occur through the insulation absorbing moisture or oil, which is subsequently carbonised by the sparking at the brushes. In faults of this description the only remedy is to expel all moisture from the commutator insulation by means of heat, and scrape out all metallic dust which may be embedded in the surface of the insulation. If this does not effect a cure, it will be necessary to dig out the insulation, as far as possible, with a sharp tool, and drive in new insulation; oil should not be used on commutators insulated with these materials, but only asbestos dust or French chalk.

(6.) **Rough and Uneven Surface of Commutator**—This fault may be due to bad adjustment of brushes, bad construction of commutator, or to neglect generally. If allowed to continue, it results in heavy sparking at the brushes, and the eventual destruction of the commutator. If due to bad construction, the only course open is to fit a new commutator; if due to the other causes mentioned, the fault may be remedied by cleaning, filing, or turning up the commutator in the manner explained in Chapter X. (Trueing Commutator).

(7.) **Segments Loose or Knocked in.**—When the segments are loose, it is an indication that the clamping ring or cone has worked loose. This should therefore be tightened up, and the commutator turned up. When the commutator receives an accidental blow, one or more of the segments is invariably forced below the level of the others. In this con-

dition the commutator is practically useless. To remedy, two courses are open: the commutator surface may be turned down to the level of the knocked-in segment, or the latter may be pulled out again to its former level, this latter being the preferable method, if it can possibly be effected. To pull out the segment, a hand vice is firmly clamped to the lug, or a loop of copper wire is passed round the conductor where it joins on to the commutator. A bar of iron to act as a lever is supported on a fulcrum over the commutator, and one end of the bar is passed through the loop or vice. On pressure being applied to the other end, the knocked-in segment can generally be brought up to its former level. The commutator can then be filed up with a dead smooth file.

CHAPTER XIII.

MOTORS.

WHILST the primary function of a dynamo is to convert, more or less efficiently, mechanical energy into electrical, that of a motor is the converse of this process, its use being to convert electrical energy into mechanical; an efficient dynamo or motor will, however, act indifferently as either, provided that the necessary mechanical or electrical energy is supplied. Formerly manufacturers were in the habit of taking advantage of this latter fact, and supplying the same type of machine indiscriminately for use for either purpose, without taking into consideration the circumstances under which they were required to work. It has now, however, become generally recognised that, as the conditions of working of a dynamo and of a motor are frequently widely different, this system is not, under all circumstances, the most efficient or desirable.

Thus we find that while under ordinary favourable circumstances ordinary type dynamos are frequently used as motors and *vice versâ*, it has now become the general practice, and more particularly in America and Germany, where the practical applications of

electricity to industrial purposes are more numerous than in this country, for manufacturers to recognise this distinction, and lay themselves open to supply machines specially designed to work solely as motors or as generators, and therefore each best adapted to fulfil the particular conditions under which they may be required to work. In order to fully comprehend the action of electro-motors, there are two points essential to their working which require consideration, these being the *armature propelling force or drag* and the *counter electro-motive force.*

Torque.—It has been already mentioned in connection with the subject of dynamo reactions that the conductors of an armature, when current is passing through them, exert an attractive or repulsive force, as the case may be, upon the stationary field magnets. In the case of a dynamo, the resultant effect of these forces is to retard the rotation of the armature against the mechanical forces tending to turn it round, which must naturally be the case, otherwise more energy would be obtained from the machine in the form of electrical than was put into it in the form of mechanical, which is contrary to the principle or theory of the conservation of energy.

In the case of a motor, however, in which practically the same condition of things obtains, in so far as the passage of the current through the armature conductors and their relation to the stationary field magnets is concerned, the resultant effect of these forces is to produce a "turning moment" or "twisting" force tending to rotate the armature, which in consequence is rendered capable of giving off mechanical energy and performing work. The force with which the

armature tends to rotate is technically known as the *torque* of the motor.

Counter Electro-Motive Force.—We have seen that when an armature is caused to rotate in a magnetic field, no matter how created, so that its conductors cut the lines of force contained in the field, an E. M. F. is induced which acts in a direction tending to stop the motion. The armature of a motor when caused to rotate by the supply of electrical energy to its terminals is subjected to these conditions, the E. M. F. induced in this case tending to *counteract* the external E. M. F., giving rise to the flow of current through the motor armature. The E. M. F. induced in the motor armature is, owing to this property, termed the *counter E. M. F.*, and its generation is, as in other cases of electro-magnetic induction, subject to the same laws. In the case under consideration the current, which a given external E. M. F. is capable of sending through the motor armature, will evidently vary with the speed of rotation of the armature, and also with the strength of the magnetic field of the motor, since both of the factors determine the value of the induced or counter E. M. F. If, while current is flowing through its conductors, the motor armature be forcibly held so that it cannot rotate, there will be no counter E. M. F. generated, tending to dam back the current, and therefore the current and also the torque or force tending to turn the armature round will attain their maximum values. If, on the other hand, the motor armature be allowed to rotate free, *i.e.*, without any load, and provided the field magnets are excited, the counter E. M. F. will have arrived at its greatest value, and the current flowing will be a minimum, just so much,

in fact, as will enable the armature to rotate against the resistance due to the friction of the bearings, &c. Other things being equal, the speed of the motor armature will be determined by the strength of the magnetic field maintained by the field magnets. If, through any cause, the strength of the latter be reduced, the armature will evidently tend to rotate faster, in order that the same counter E. M. F. may be induced to maintain the current at its former value. If, on the other hand, its strength be increased, the speed will evidently tend to fall in order to compensate for the increased value of the counter E. M. F. generated. At one time, inventors busied themselves in devising means to overcome this counter E. M. F., which they imagined was detrimental to the efficient working of electro-motors, but it is now generally recognised that the self-regulating properties and efficiency in working of this class of machine is directly due to its influence, in enabling the motor armature to take current in exact proportion to the work to be performed at any given moment.

Classes of Motors.—As in the case of dynamos, motors may be divided into classes in accordance with the methods of arranging their field coils in relation to the armature circuit. Motors intended for practical work at the present time may be arranged as follows:—

Series Motors.
Shunt Motors.
Compound Motors.
Differential Motors.

Each of these types of motors has its own special advantages for particular classes of work.

Series Motors.—In this class of machine the field coils are arranged in series with the armature, the connection to the mains supplying the energy being as represented in Fig. 101. The excitation of the field in this type of motor being dependent on the current passing through the armature, it possesses the characteristic of great starting torque. Owing to the same circumstance, however, when the current in the mains is supplied at a constant potential, the speed tends to fluctuate with a varying load. The performance of a series motor under varying loads, when the current is supplied at a constant potential, which in practice is usually the case, will be understood by reference to Fig. 102, which represents the *mechanical characteristic* of such a motor under these conditions, the relation between speed (N) and torque (T) being graphically shown. Under the conditions of supply mentioned above, when the armature is at rest there will be no counter E. M. F. existing in its windings, and therefore the current passing through the armature and field coils will be a maximum; the torque, in this class of motor, being dependent solely on the current passing, will also reach a maximum. As soon, however, as the armature begins to rotate, the counter E. M. F., generated by the motion, tends to dam back the current, and therefore as the speed rises the torque tends to fall, until a condition of things is arrived at when the torque and load are mutually balanced, when the speed will remain constant so long as the same condition of things

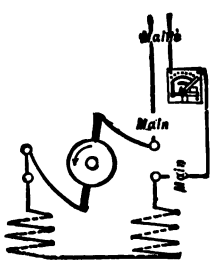


FIG. 101.

continues. If a series motor, under the particular conditions of supply mentioned above, be started without any load, or, if while working, the load be suddenly taken off, the speed tends to increase to a dangerous extent, as indicated by the curve rising rapidly upwards. The reason for this abnormal increase in speed lies in the fact that the armature upon speeding up tends to weaken the field to an increasing

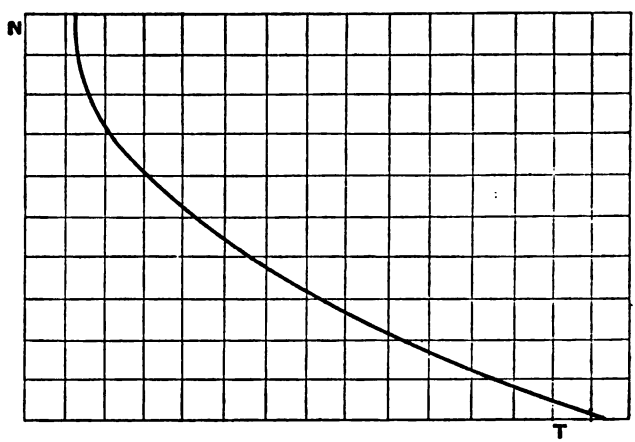


FIG. 102.

degree, and as this necessarily implies a successive further increase of speed to compensate for the fall in the value of the counter E. M. F., the speed is quickly raised to an excessive extent, and the armature may even be eventually destroyed, if its construction is not sufficiently strong to withstand the influence of the centrifugal forces brought into play. For electric traction purposes, where the motor may be either coupled

direct or through the medium of gearing to the shaft, and where constancy of speed is not requisite nor indeed desirable, the series motor, combining as it does these qualities, with great starting torque, fulfils the conditions admirably, and is now exclusively employed for this service. Owing to its "racing" propensities it is not, however, well adapted for cases where the load is liable to be taken off suddenly, as may happen in belt-driven service, if a belt breaks or comes off, or, in the case of a motor coupled to a pump, if the water fails.

Shunt Motor.—This type of motor is probably more extensively used than any other, fulfilling as it does the more general commercial requirements of approximately constant speed under varying loads, with moderate torque at starting. The connections of the field coils and armature to one another and to the mains are as represented in Fig. 103. This class of motor being usually employed on constant potential circuits, and the field coils being arranged as a shunt to the armature and service mains, the exciting current, and therefore the field, tends to remain constant. The speed, and consequently the counter E. M. F. of the armature, being influenced by these conditions, also tends to remain constant, or nearly so, under varying loads. The mechanical characteristic of the shunt motor, showing the relation between the speed (N) and torque (T), is illustrated in Fig. 104. From this it will be seen that this motor possesses very fair self-

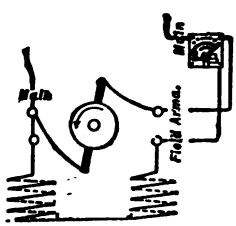


FIG. 103.

regulating properties, the speed under fluctuating loads remaining practically constant throughout a considerable range, after which, as a greater load is put upon the machine, the speed is reduced somewhat, but for ordinary purposes this reduction being small, and not exceeding 9 per cent. in the case of good motors, is not specially disadvantageous. If necessary the drop in speed may be compensated by means of a hand regulator placed in the shunt field circuit.

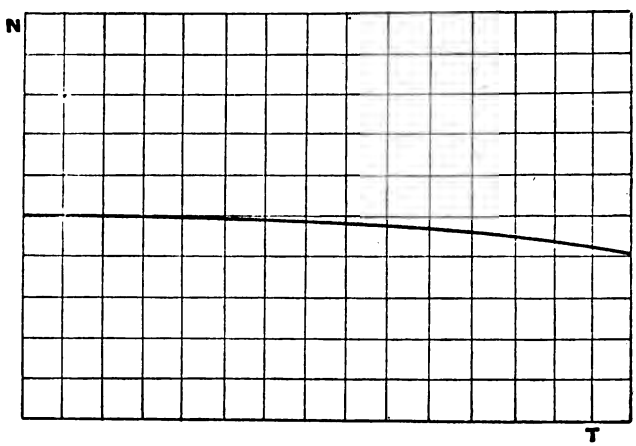


FIG. 104.

Compound Motors.—In this motor, the connections of which are as represented in Fig. 105, the field coils are arranged in a combination of shunt and series windings. The motor is in fact a shunt machine with the addition of a few turns in series with the armature, the effect of which is to strengthen the field during times of heavy or variable loads, and at starting, and thus provide the additional torque required

under these circumstances, in which the ordinary shunt machine is deficient. The compound motor, being thus a combination of the two common types of motors, viz., shunt and series, partakes of the properties of each; owing to the influence of the series coils, the great starting characteristics of the series motor are retained, while the presence of the shunt windings prevents the armature attaining any dangerous speed or "racing," and in most cases the speed is practically constant under all loads within the capacity of the machine. Owing to these qualities the compound motor is usually employed in circumstances where a fairly constant speed is required, combined with extra powerful torque at starting, as is the case in driving lifts and hoists, punching and shearing machines, printing presses, and winding and hauling machines.

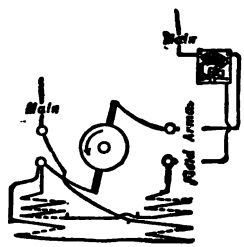


FIG. 105.

Differential Winding.—This motor is merely a compound machine, with the series coils so arranged that the current passing through them from the armature tends to weaken the fields when the load comes on, in place of strengthening it, as in ordinary compound machines. The object of this motor is to provide an absolutely constant speed under circumstances where the use of the ordinary shunt machine would be inadmissible, owing to the slight fall in speed which takes place with an increase of load, the effect of the weakening of the field being to compensate for this drop in speed. This class of machine is not

very frequently employed, partly for the reason that there are difficulties connected with the starting arrangements, and also for the reason that in most cases the shunt motor fulfils all ordinary requirements in so far as constancy of speed is concerned.

Construction of Motors.—While, as previously mentioned, every dynamo will work efficiently as a motor if electrical energy is supplied to its terminals, in many cases the same design and type of construction as applied to dynamos is not always applicable to motors. One of the principal reasons for this divergence lies in the fact that a dynamo may be regarded as a fixed and stationary piece of machinery, the surroundings being in most cases specially adapted to ensure that the machine will work efficiently, and free from the presence of dust and dirt and moisture and other deleterious influences. On the other hand, a motor is very frequently required to give off mechanical energy whilst bodily in motion, and being carried from place to place, and as a rule the exigencies of practical work requires that a motor be fixed as near as possible to its work, and therefore in situations frequently not well adapted either for the efficient or the lasting performance of its duties if constructed upon the ordinary lines of dynamo design. In the former case, *i.e.*, that of a dynamo, light weight and compactness of form are not essential; in the latter these qualities are indispensable. Motors are also, from the very nature of their employment, liable to be subjected to stresses and rough usage, and to the further deleterious influences of wet and dirt of all descriptions, which circumstances naturally involve extra precautions being taken, and extra strength

being provided, to resist these injurious influences. In order to fulfil as far as possible these varying requirements in practical everyday working, motors are now constructed and arranged into two main types, viz., (1) *Open Type Motors*, and (2) *Enclosed Type Motors*. It is of course not possible to draw a hard and fast line separating these two types, as owing

Fig. 106.

to various circumstances connected with their working they graduate through varying degrees, from *enclosed* to *partially enclosed*, to *open type*.

Open Type Motors.—In dry situations and places where accumulations of dirt and dust are not liable to occur, it is the general practice to employ this type of motor, which may be regarded as merely an ordinary dynamo, provided with starting box and regulator,

and having its construction altered in various minor details to suit the special conditions. A motor of this description, provided with starting box and resistance, is illustrated in Fig. 106, and calls for no special remark.

Enclosed Type Motors.—For all situations where the motor is liable to rough usage or accidental damage, and the influence of wet and dirt, &c., this type of motor is undoubtedly the most suitable, and owing to most of the principal fire insurance companies expressing a preference for, and, in some cases, insisting upon their use, they are now more extensively employed than any other type. They derive their cognomen from the fact that the framework supporting the bearings and field magnets entirely encloses and protects the armature, field coils, and commutator, &c. The method of arranging the outer protecting casing in order that these objects may be carried out in the most efficient manner possible, differs of course with different makers, and in accordance with the special circumstances under which the motor is required to work, but the general construction and arrangement of the parts of this class of motor will be understood by reference to Fig. 107, which represents one of the best patterns of enclosed motor at present on the market. The

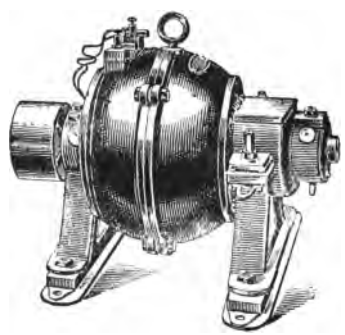


FIG. 107.

peculiarity of this motor lies in the form and construction of the field magnets, which, when built up, form an outer casing of spherical form, entirely enclosing and protecting the armature, field coils, commutator, and brushes, &c.

The internal arrangement of the motor will be understood by reference to Fig. 108, which gives a sectional

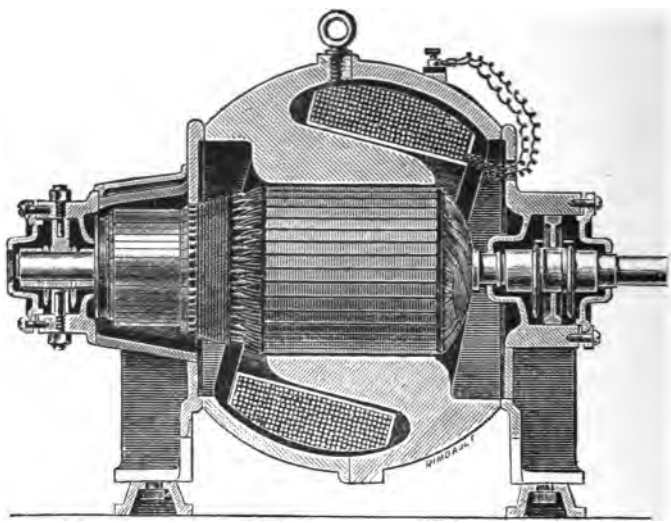


FIG. 108.

view. As will be observed, the field magnet is built up in halves, bolted together, each half consisting of a hollow hemispherical steel casting provided with a claw-shaped projection. These projections form the pole pieces of the field magnet, and when the two hemispheres are fitted together, a hollow chamber is formed concentrically with the outer casing, within

which the armature rotates. A special feature of this design is the use of a single exciting coil, which entirely surrounds the projecting pole pieces and the armature. This exciting coil, which takes the form of a ring, as shown in Fig. 109, is wound upon a former, and previous to being fixed in place is thoroughly insulated with tape and varnish, &c., and closely fits the hollow space which exists between the outer shell and pole pieces. The armature is of the slotted drum pattern, and the shaft revolves in bearings supported by brackets bolted to the spherical outer casing, which is specially formed to enable this to be effected. The bearings are adjustable, and are provided with automatic lubricators of the revolving ring type, as illustrated and described on page 84. A view case, with hinged cover, is fitted over the commutator so that the latter, together with the brushes, may be readily inspected. The brushes are of carbon, and are kept pressed against the commutator, butt end on, by means of a simple spring arrangement. The whole design forms a most compact and solid construction, capable of withstanding a large amount of rough usage without the efficient working of the motor being interfered with.

FIG. 109.

Traction Motors.—One of the latest forms of this class of motor, which may be regarded as a specialised type of the enclosed motor, evolved to meet the

exacting conditions of working to which its use necessarily subjects it, is illustrated in Fig. 110. The motor, which is technically known as the G.E. 800, consists of two steel castings, which form at once the frame of the motor supporting the bearings and the yoke of the field magnets. The castings are hinged at one

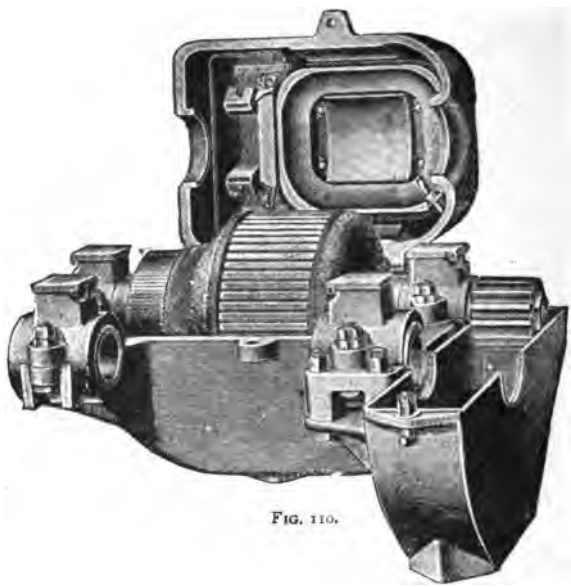


FIG. 110.

side and bolted at the other, and when closed form a dust-proof and watertight casing, entirely enclosing and protecting the armature, field coils, commutator, &c. The framework is constructed in two forms, viz., one in which the top half is arranged to be lifted for the purpose of inspecting or handling the armature and parts from above, on the floor of the car, and

having the suspension on the lower portion of the frame, and the other form arranged for handling the armature from below, in the examination and cleaning pit, and having the suspension arranged on the upper frame. For the purpose of permitting ready access to the commutator and brushes, &c., the upper half of the frame is provided, at the commutator end, with a large opening, which, when the machine is working, is covered with a hinged lid, to exclude dust and dirt, &c.

The field magnets of the motor are of the multi-polar type, being provided with four poles, two of which are consequent and two salient poles. Two field coils only are, however, used for exciting the field magnets, these being arranged to slip over the projecting salient pole pieces cast on each half of the frame.

The field coils are specially arranged to be easily removable in case of necessity. They are composed of windings of copper wire, insulated with asbestos, and previous to being fixed in place, are wound to the proper shape upon a former, and rendered thoroughly waterproof by means of a covering of canvas, coated with japan, and afterwards well baked. The coils after being fitted are secured in place by means of suitable flanges fitting over the pole pieces. The armature is of the slotted drum pattern, and the windings being composed of machine-made coils, are easily removable for repairs or renewal. The motor is fitted with the usual form of single reduction gearing now generally adopted for traction service.

Operating Motors.—In operating motors of any considerable size, whether connected to the public

supply mains of a central generating station for combined lighting and power service, or to power service mains only, there are certain precautions to be observed in starting, stopping, and regulating the motor, in order that the efficiency of the supply, and indirectly the working of other motors and lamps connected to the mains in the immediate neighbourhood, may not be affected by abnormal variations of pressure, and also to prevent any danger of the motor itself being subjected to detrimental mechanical shocks and excessive temperatures in the working parts. The reason for these precautions will be apparent when we consider that a motor armature when at rest offers a practically negligible resistance, and if connected to the mains direct, under these conditions, at the normal pressure, would cause such a heavy rush of current through the armature, that not only would the machine itself be subjected to an excessive temperature, or even a burn out, but in the event of the supply of energy being taken from the public mains, the pressure in the latter in the immediate neighbourhood would be at once reduced. In the latter case, even if the fall in pressure were momentary only, its effect would still be appreciable in the service mains of other consumers, and particularly if lighting and power service were combined. The same remarks hold good in the case of a motor, while fully loaded, being suddenly switched off from connection with the mains; under these circumstances the pressure would immediately rise. In connection with this subject it may be mentioned that in order to obviate any trouble arising from the variations of pressure due to fluctuations of load, while a motor is working and deriving

current from public supply mains, it is the practice in many towns to provide the motor with a heavy fly-wheel, keyed on to the armature shaft. The action of the fly-wheel is to cause, by virtue of its momentum, all variations in current to be gradual, and thus the effect upon the pressure, and consequently the lamps, is practically *nil.* From this it follows, that in order to start a motor without the danger of affecting the neighbouring supply service, and for the safety of the motor itself, it is first of all necessary that the motor be started gradually from rest, a small amount of current only being allowed to pass through the armature in the first instance, gradually increasing by small increments at a time, sufficient time being allowed to elapse between each increment to enable the supply to accede to the demand and attain stability, until the motor is fully speeded up. In stopping a motor, the converse evidently holds good, the current needing to be reduced gradually by small decrements spread over a certain period of time, depending on the power and size of the motor, until the speed of the armature is reduced.

In practice, the most common method of ensuring that the correct amount of current is taken by a motor at starting is to arrange a resistance in series with the motor and the service mains which on starting may be fully inserted, and then gradually cut out of circuit in successive steps as the motor speeds up; being again gradually re-inserted step by step on stopping. In the case of series motors, this resistance must evidently be arranged in series with the armature and field coils, and in the case of shunt motors in series with the armature only, the shunt field winding in the latter

case being connected immediately, direct to the mains, in order that the field magnets may be fully excited, previous to allowing any considerable current to pass through the armature. From this we see that the chief precautions to be observed on starting, stopping, and regulating motors of whatever description, whether shunt, series, or compound, are, that the initial current passing through the motor at starting shall not exceed a given amount, both to prevent mechanical shock to the motor and variations of pressure in the mains, and that this current shall be varied by small increments or decrements as the case may be, spread over a considerable period of time, depending upon the power of the motor. In addition to these precautions, which may be regarded as incidental to the practical *manual operation* of motors, there are others to be observed in the permanent *connection* of the motor to the mains. These latter may be regarded as safeguards to ensure the safety of the motor against destruction through causes which to a certain extent are beyond the control of the operator or attendant, such as abnormal rushes of current consequent on an overload of the motor, or to the failure and subsequent restoration of pressure in the mains. In this latter circumstance, the motor, if shunt wound, would probably be destroyed; and if series wound, if not altogether free from this danger, might result in the motor being self-started at a time and under circumstances which would endanger the lives of workmen and others engaged about the motor or the machinery to which it is connected. To prevent either of these events occurring, it is the common practice to insert "circuit-breakers" and other classes of automatic

switches actuated by electro-magnetism into the circuit of the motor, so that the latter may be automatically switched out of circuit if the current increases beyond, or the pressure falls below, a certain predetermined limit.

Motor Starters.—To enable the current at starting and stopping to be conveniently controlled within the given limits as mentioned above, it is the usual practice to provide *Motor Starters* to all motors exceeding one-quarter horse-power. There are innumerable types of these appliances on the market, mostly of American design or origin, and they usually consist of resistances composed of coils of German-silver or platinoid wires, contained within perforated or fireproof metal boxes. The coils are connected at intervals to metal studs, fixed upon an insulating base, and the resistance in circuit, and consequently the current, may be varied as may be required by means of a handle and contact bar which moves over the studs and inserts or removes a greater or less amount of wire into circuit. A starter of this description, which may also be used as a regulator, is illustrated in Fig. 111. This may be regarded as the simplest form of motor starter, but considered as such it cannot be said to fulfil all the requirements demanded of a modern appliance of this description. In order to secure the greatest efficiency in working, it is necessary that all

FIG. 111.

resistance be cut out of circuit as soon as the motor has fully started up, to be again inserted when stopped, and in this form of starter this is necessarily left to be effected by the attendant, who may either be careless or inexperienced and may probably leave the contact arm in some intermediate position. A more efficient method of ensuring that the resistance is correctly arranged in circuit on starting and stopping is that provided by the form of starter illustrated in Fig. 112. In this pattern the resistance coils are arranged as in the preceding form, but the contact arm is provided with a spring which tends to permanently hold the arm in the "off" position, so that all resistance is included in circuit. In starting, the arm is moved slowly over the contact studs until, when the final point is reached by which all resistance is cut out of circuit, the arm is held in place by means of a clip; it is thus impossible for the arm to be left in any but those of full "on" or "off" positions. The method of arranging the starter in connection with the motor and service mains is illustrated diagrammatically in Fig. 113.

FIG. 112.

Automatic Release Starters.—Whilst the preceding type of starter fulfils all ordinary requirements in so far as the manual starting and stopping of motors is concerned, as previously mentioned, it is preferable, both for the safety of the motor itself and

for those employed about it, that some form of electro-magnetic device be provided to enable the motor to be automatically disconnected from the mains, should either an abnormal increase of current or a fall in pressure take place. In the case of large-sized motors, exceeding—say—ten horse-power, where a heavy current is liable to be suddenly switched out of circuit, it is the usual practice to arrange one or other of the different forms of circuit-breakers, as used in dynamo service, in some part of the circuit; for smaller powers, however, the automatic safety devices may advantageously be combined with the starter, a combination of this description being illustrated in Fig. 114. In this form of starter the contact arm is provided with a spiral spring for holding it in the "*off*" position, as in the type of starter described above, but in place of a clip for holding it in the "*on*" position an electro-magnet is provided. This electro-magnet is connected in parallel with the motor armature,

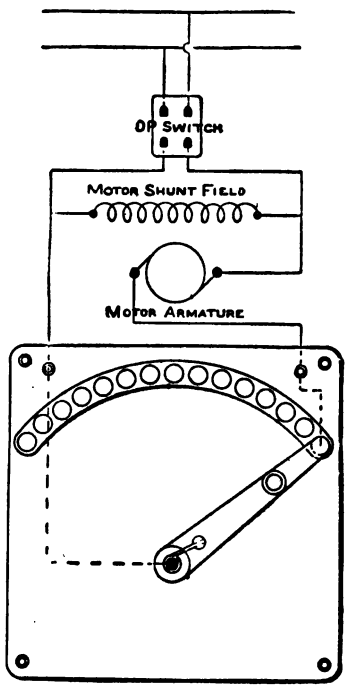


FIG. 113.

and, when the machine is working under normal conditions of pressure, holds the contact arm in place by virtue of its attraction for an iron keeper or armature fixed to the end of the arm. If at any time the pressure fails, or falls below a certain limit, the electro-magnet is weakened, when the force of the spring causes the arm to fly back to the "off" position. To enable the motor to be automatically disconnected from the mains, in the event of an abnormal increase of current due to an overload, a second electro-magnet is con-

MOTOR WORKING. MOTOR STOPPED.

FIG. 114.

nected in series with the motor armature, and arranged to break the circuit of the electro-magnet holding the contact arm, which accordingly flies back to the "off" position. A diagram showing the connections of the starter and motor to one another and to the mains is given in Fig. 115.

Automatic Slow Starters.—Another useful type of starter is that arranged with the object of preventing the attendant switching the motor into circuit too rapidly, and before it has had time to fully speed up. In this pattern, which is illustrated in Fig. 102, and

which is practically a combination of the spring starter (Fig. 112), and the automatic starter (Fig. 114), two contact arms are arranged to work upon a common centre or spindle. One of these arms is for the purpose of removing or inserting resistance into or out of circuit, and its action is similar to that of the spring starter (Fig. 112), the contact arm, when all resistance is cut out of circuit, being held in place by means of a clip. The other, or switch arm, is provided with an iron keeper, as in the automatic starter, and both arms are connected together by means of a spring which tends to hold them at their smallest angle. Two electro-magnets are provided and arranged as in the preceding type for the purpose of automatically disconnecting the motor from the mains in the event of the pressure falling or the current rising beyond a predetermined limit. At the same time one of these electro-magnets, in conjunction with the iron keeper and the spring connecting the two arms, deter-

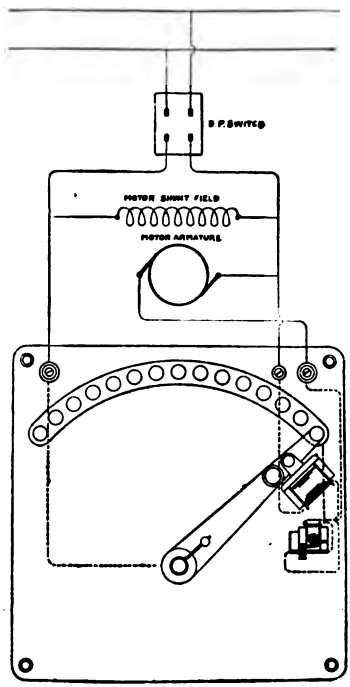


FIG. 115.

mines the interval of time which must elapse before the motor is fully switched into circuit. This is effected in a very simple manner. The switch arm, to which the iron keeper is attached, being moved over towards the electro-magnet completes the motor circuit, and the electro-magnet, being thereby excited, the arm is held in place. The contact arm is then moved over the studs, and the resistance gradually cut out of circuit; if, however, this movement is effected too rapidly, the spring connecting the two arms tends to

MOTOR WORKING. MOTOR STOPPED.

FIG. 116.

pull the switch arm from its contacts and the circuit is thus broken. If the pressure falls or the current increases beyond the safe prescribed limit for the motor, the switch arm is released and the motor cut out of circuit in the ordinary manner. Fig. 117 illustrates the method of connecting this type of starter and the motor to the mains.

Starting and Stopping Motors.—Provided that a motor is connected to the service mains in the manner as illustrated in the preceding diagrams, and use is made of any of the spring type of starters as

described above, starting a motor is the simplest possible operation. It is only necessary to see that the contact arm is in the "off" position, then close the D.P. switch, after which the contact arm is moved over the studs, passing quickly from one stud to the other, but allowing the arm to remain for a brief interval, say three or four seconds, upon each stud to allow the motor time to speed up, until all resistance is cut out of circuit.

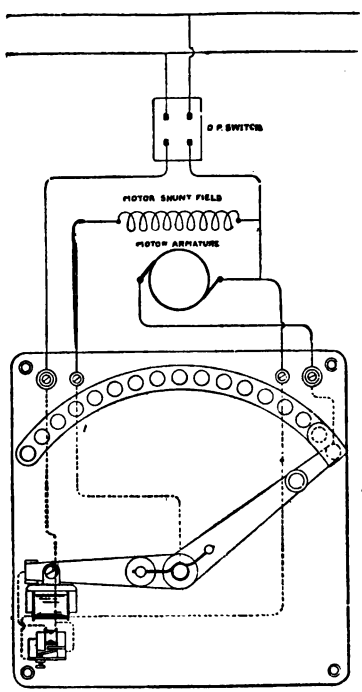


FIG. 117.

In stopping, the reverse process must be gone through, *i.e.*, if the motor is of large size, the resistance being gradually cut out of circuit and the D. P. switch finally shut off. In the case of large shunt, compound, or differential motors, where the field coils are composed of a large number of turns of fine wire, it is especially necessary to see that the shunt circuit is not broken by any means, as if this happens, the insulation is liable to be destroyed through the momentary high tension

"extra" current induced on breaking the circuit. If the connections are arranged as illustrated in the diagrams, however, there is not much chance of this accident occurring, unless the brushes are lifted from the commutator while the machine is working or when stopping.

Faults in Motors.—In addition to these irregularities in working, which may be regarded as peculiar to motors alone, they are also subject to most of the faults already enumerated as occurring in dynamos; owing, however, to the rougher usage experienced, and the generally more unfavourable conditions under which motors are required to work, these latter faults are usually of a more pronounced type.

Excluding those faults which may be said to be common to both dynamos and motors—such as sparking at brushes, excessive heating, noise, &c.—and which have already been considered in the preceding chapter, the irregularities to which a motor is subject, and which, if already mentioned as occurring in dynamos, have a different origin in motors, may be enumerated as follows:—

A. Failure to start.
B. Irregularities of speed.

A. *Failure to Start.*—This fault, which is liable to occur in a motor of any description, is analogous to failure to excite in a dynamo, and is liable to be produced by any of the causes mentioned in connection with the latter fault, excluding (5) insufficient speed, and (8) insufficient residual magnetism only. When a motor fails to start in the first instance, it should be ascertained if a supply of electrical energy

is available in the mains. This may readily be discovered by means of a voltmeter, or if low-tension service by means of the fingers bridging across the main terminals. If the supply of energy is present the contact arm of the starter should be moved into such a position that all resistance is inserted into circuit with the motor. This is important, as the motor may chance to start suddenly whilst endeavouring to ascertain the cause of the stoppage, and probably lead to unpleasant results. Having closed the D.P. switch, if the motor fails to start, it will be advisable to remove the load if possible, as the failure may arise from an overload of the machine.

This being effected, and the motor not starting, the terminals of the latter should be tested by the means already described for the presence of a difference of potential. If this is non-existent, a broken circuit or a defective contact may be looked for in the main fuse, switch, or starting box. The resistance coils of the latter, through the heat developed, frequently break in positions out of sight. If a defective contact of this nature cannot readily be seen, the contact arm should be moved slowly over the studs, as it is possible the broken coil may be cut out of circuit by this means. If a difference of potential exists between the motor terminals, the field magnets will, if shunt or compound wound and in good order, be excited, which may be ascertained by means of a bar of iron. If no magnetism is present it will of course indicate a broken or bad connection, either between the terminals of the field coils, or one or other of the coils themselves. If the bar pulls strongly, the position of the brushes upon the commutator in regard to the

neutral points should be ascertained, and the rocker adjusted, if necessary, to bring them into their correct positions. If this fails to start the motor, the connecting leads from the motor terminals to the brushes and the brushes themselves should be carefully examined for broken or bad connections, and defective contact of the brushes with the commutator. In the latter case, it may arise from a dirty state of the commutator, or owing to the brushes not being fed up properly. If due to these latter causes, pressing the brushes down upon the commutator with the fingers will probably start the motor. If the failure to start arises from none of these causes, it is probably due to the field coils acting in opposition, or to a short-circuited armature. This latter remark applies, however, more especially to motors provided with drum armatures. A ring armature under these conditions will, in most cases, start all right, but will give rise to violent sparking at the commutator.

B. *Irregularities of Speed.*—The following remarks apply more particularly to that class of motor (shunt, compound, or differential) supplied with current at a constant potential, under which conditions the natural characteristics of the machine is to maintain a constant or approximately constant speed under all variations of load within the capacity of the motor. The speed of a series motor under these circumstances is liable to fluctuate with the load, and all motors of this description, when used for purposes where the load is liable to be suddenly removed, ought to be provided with a resistance, or rheostat, of some description, connected in series with the motor, and of such amount that when fully inserted the speed is kept within reasonable

bounds. In the case of a motor of the former description, an *excessive* speed is most frequently due to a short circuit of a more or less partial description, or a defective contact in the shunt field circuit, either of these faults having a tendency to reduce the strength of the magnetic field, and therefore to increase the speed of the armature. The fault in either of these cases may be remedied by following the procedure described in the preceding chapter. In those machines provided with a ring armature, a short circuit of a portion of the armature coils, either at the commutator or in the interior of the armature, has a tendency to cause an increase of speed. When the motor gives an abnormally *low* speed, it indicates either an overload or a short circuit of some description, or more probably a defective contact in the armature circuit. When due to either of these latter causes, the fault is most likely to occur in the brush-holders, or the brush-rocker, or in the brush-leads, which should be tested as already explained, and the fault remedied. The speed of motors is also liable to be influenced by the causes mentioned in connection with dynamo speed irregularities, viz., Section E, defective bearings, and (5) armature rubbing against pole pieces. If a motor, not intended to reverse, revolves backwards when started, it will be necessary to reverse the field connections.

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